

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS

RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF

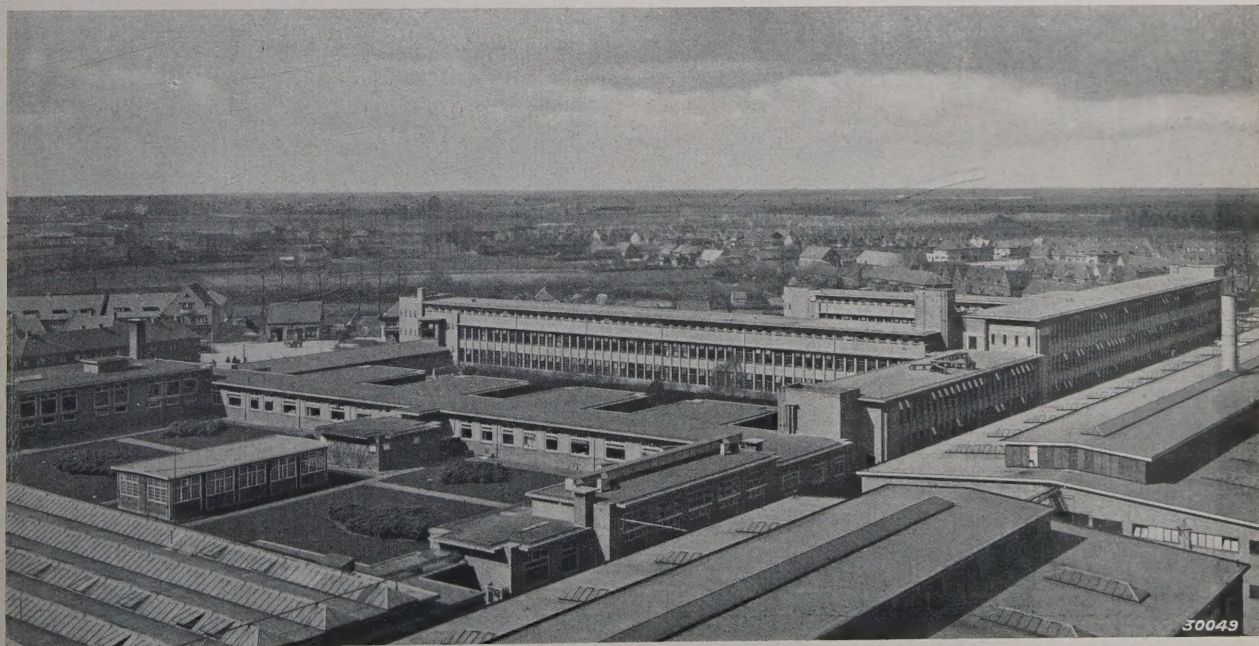
N.V. PHILIPS' GLOEILAMPENFABRIEKEN

EDITED BY THE RESEARCH LABORATORY OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, HOLLAND



On January the first 1939 twenty five years had passed since G. Holst joined the Philips company. This date marks the beginning of systematic scientific research in our Physical Laboratory. In this period the scope of this work has developed in manifold directions and we might say that the contents of this review are to be considered as a proof of his activity.

For this reason, we want to commemorate this historical fact and to reproduce for the benefit of our readers photographs of the Laboratories and of its Director Prof. Dr. G. Holst.



A FILM PROJECTION INSTALLATION WITH WATER-COOLED MERCURY LAMPS

778.553 : 621.317.31

The water-cooled mercury lamp is a light source of great intensity, and is therefore suitable for the projection of films. Compared with the carbon arc the mercury lamp has the advantage of smaller dimensions and of much less heat development. Moreover it is free of certain disadvantages connected with the use of the carbon arc, such as the change of position and size of the crater, and the sputtering of small particles. The employment of the water-cooled mercury lamp has made it possible to construct a very compact apparatus for the reproduction of films. The apparatus is described in this article. Special attention is paid to the factors which are important in the construction of an illumination objective for water-cooled mercury lamps.

Introduction

The high intensity of illumination of the film which is necessary for cinema projection requires a very intense light source. It was therefore to be expected that the light source would be used for this purpose which had the greatest brightness known, namely the carbon arc. This light source, however, has various technical objections. The crater changes in shape and size; and, moreover, tiny particles are thrown out of the arc, which soon cause a decrease in the reflecting power of the condensing mirror.

These objections have led to the attempt to replace the arc lamp by an electric filament lamp. With the increasing size of the cinema theatres it was, however, found impossible to satisfy the also increasing demands of the public as to brightness of the picture. The following calculations may serve to define the requirements made of a light source for film projection.

In *fig. 1* the ordinary arrangement for film projection is given. *O* is the area of the source of light with the brightness *B*. By means of this light source and a condenser, for which a mirror is often used, the film window *G* with the area *g* is uniformly illuminated. We assume that the condenser has such a large aperture that the objective is completely filled by the beam which passes through every point of the surface of the film. The maximum angle of radiation *w* is therefore determined by the aperture of the objective.

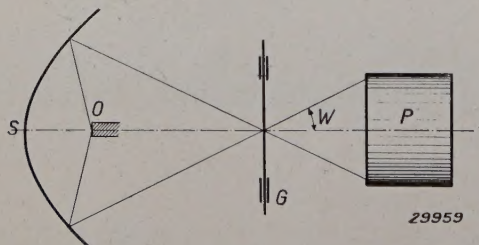


Fig. 1. Ordinary arrangement for film projection. *O* light source, *S* reflector, *G* film window, *L* projection lens.

According to a well-known theorem of geometrical optics, in an ideal optical system, without absorption or scattering, the brightness of every cross section of the beam, observed in the direction of the path of the rays, is the same as that of the source of light. By applying this theorem to the surface *g* in *fig. 1* we find for the light flux Φ , through the projection lens *P*:

$$\Phi = K g B \pi \sin^2 w, \quad \dots \quad (1)$$

where $K < 1$ and is a factor which accounts for the losses by absorption and reflection.

The surface *g* of the film window is fixed, it measures $1.57 \times 2.02 \text{ cm} = 3.17 \text{ sq.cm}$. The maximum angle of radiation is determined, as mentioned above, by the relative aperture¹⁾ of the projection objective. For an objective with the relative aperture 1 : 2, $w = 14^\circ$; $\sin^2 w = 0.0585$. The efficiency factor *K*, roughly estimated, is $\frac{1}{2}$, and becomes $\frac{1}{4}$ due to the cutting off of light by the rotating sector.

When these values are substituted we obtain:

$$\Phi = \frac{1}{4} \cdot 3.17 \cdot \pi \cdot 0.0585 \cdot B = 0.146 B \cdot \quad (2)$$

The greatest brightness which can be obtained with a filament lamp for projection is about 4000 c.p./sq.cm; with this one should therefore be able to obtain a light flux of 580 lm of the screen, according to equation (2).

Actually this value is reduced by aberration defects of the condenser, which must have a very great relative aperture, by the action of shadows from the fixtures in the path of the rays, by scattering of the light at boundary surfaces, etc., so that in practice the light flux is not much more than about 400 lm.

In the case of transportable installations and

¹⁾ The relative aperture indicates the ratio of the effective diameter (diaphragm opening) to the focal length of the lens.

small cinemas, where the area of the screen is only a few square metres, this light flux is sufficient; in large cinemas, on the other hand, the required light flux may be five to ten times the above value. If a screen surface of 30 sq.m. is taken and an intensity of illumination of 100 lx, the required light flux is 3 000 lm.

It is therefore understandable that a light source has been sought with a greater surface brightness than a filament lamp and easier to operate than the usual carbon arc.

Such a light source was discovered several years ago in the water-cooled mercury lamp, which easily matches the carbon arc and even the so-called "high-intensity" arc in brightness. This light source has none of the above-mentioned disadvantages and has moreover the advantage of developing much less heat than the carbon arc.

Because of the necessity of water cooling, and because of the linear form of the light source, new problems were presented which made it necessary to consider anew the construction of the illumination objective. On the other hand the small dimensions of the mercury lamp and its slight heat development offered new possibilities for the construction of the whole projector. These considerations have led to the construction of an entirely new installation for film reproduction which makes full use of the advantages offered by the water-cooled mercury lamp.

The most important parts of this installation will be dealt with in the following.

The light source

The properties of discharges in mercury vapour at a high pressure have been dealt with repeatedly in this periodical²⁾. It has been found that the efficiency of this light source increases steadily with the energy supplied per unit of length of the column. For that reason the mercury discharge is economically very suitable as a light source of high intensity. To obtain such a source it is necessary to develop a large amount of light within a small space, and this is a way of promoting the efficiency.

A large supply of energy per unit of length of the column means a high value of the product of potential gradient (volt/cm) and current. Since too high a current is undesired (because of cathode losses) provision must be made for a high value of the potential gradient, and this is possible by keeping the diameter of the discharge tube small.

On this principle, short, thin discharge tubes are obtained, which dissipate a large amount of energy. The increase of temperature and internal super-pressure are pushed as far as the tube can stand.

The mercury lamp for film projection dissipates an energy of 1000 W over a length of 12.5 mm between the electrodes. It has an internal diameter of 1.8 mm and an external diameter of 4 mm. The walls are of quartz and are cooled with water. Two tungsten wires led in through the ends of the tube serve as electrodes. In addition to a small amount of mercury the tube contains an inert gas filling of low pressure. This inert gas is necessary for ignition.

For use in film projection the tube must be fed with direct current. A transformer and a rectifier are used for this purpose. The most important data are given in the table below:

Table I
Data of the water-cooled mercury lamp

Length of the discharge	12.5 mm
Internal diameter	1.8 mm
External diameter	4 mm
Pressure of the mercury vapour	100 Atm.
Power { mercury lamp	1 000 W
{ transformer + rectifier	500 W
Current	2 A
Working Voltage	500 V
Ignition voltage	800 V
Light flux	60 000 lm
Surface brightness in the axis of the discharge	57 000 c.p./sq.cm.
Efficiency	60 lm/W

The optical system

The existing systems for picture projection can be divided into two groups:

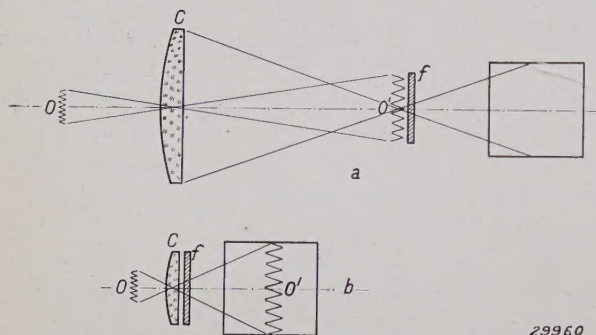
- a) the film projection system;
- b) the lantern slide system.

Both systems consist of a light source, a condenser which concentrates the light radiated on the diapositive, and a projection lens which gives the image of the illuminated diapositive on the screen. There are, however, fundamental differences between the two systems in dimensions and in arrangement of the parts.

The requirements made in the projection of films and of lantern slides are to a certain extent opposite to each other. With films one is concerned with very small surfaces and very high light intensities, and therefore with a very great heat development in the neighbourhood of film and light source. This makes it impossible to have the condenser and the other parts of the optical system too

²⁾ Cf. also the article: Water-cooled Mercury Lamps, Philips techn. Rev. 2, 165, 1937.

small, or to place them too close to the light source. A scheme of construction is therefore chosen in which the lenses and mirrors have reasonably large dimensions and are reasonably far away from the light source, and the film window is placed at the point where the beam, emitted from the light source and concentrated by the condenser, has the smallest diameter. This is about the point where an image of the light source is formed by the condenser (see *fig. 2a*).



29960

Fig. 2. Two systems of projection:

- The ordinary system for film projection. The film is situated about at the spot where the light source O is focussed by the condenser C .
- The usual system for the projection of lantern slides. The slide is directly behind the condenser. With the same size of diapositive the arrangement b permits a much more compact construction than the arrangement a .

In the projection of much larger lantern slides the required light flux can be attained with a much lower intensity of illumination of the slide, than is necessary in film projection. The heat development is not so great that minimum dimensions must be prescribed for the system, and in order to save space the condenser is made as small as possible. With respect to the position of the slide this means that the narrowest part of the beam is no longer chosen, but on the contrary, exactly the place where the beam has its greatest diameter, *i.e.* immediately behind the condenser (see *fig. 2b*).

A further very important advantage of this arrangement is, that it is much easier to obtain a uniform illumination of the object to be projected than with the arrangement for film projection. In the arrangement for film projection the light source is focussed on the film and the distribution of brightness over the film therefore more or less corresponds to the distribution of brightness over the surface of the light source. This latter must therefore be uniform over a sufficiently large part of its area having the shape of the film window. In the arrangement for the projection of lantern slides no such strict requirements are made as to size and distribution of brightness of the radiating surface.

Summarizing, we may say that the arrangement according to *fig. 2a* has the advantage of permitting a much greater heat development than that according to *fig. 2b*. On the other hand it has the disadvantage that very definite requirements are made as to form and brightness distribution of the light source.

If, instead of a filament lamp or an arc lamp, a mercury lamp is used, then because of the water-cooling the heat development is of no importance. The advantage of the arrangement of *fig. 2a* therefore loses its importance. The disadvantages of this arrangement now become very evident. Since the radiating column has a pronounced oblong shape (1 cm by 1 mm wide) it is difficult to focus it on the film window in such a way that the latter is uniformly illuminated.

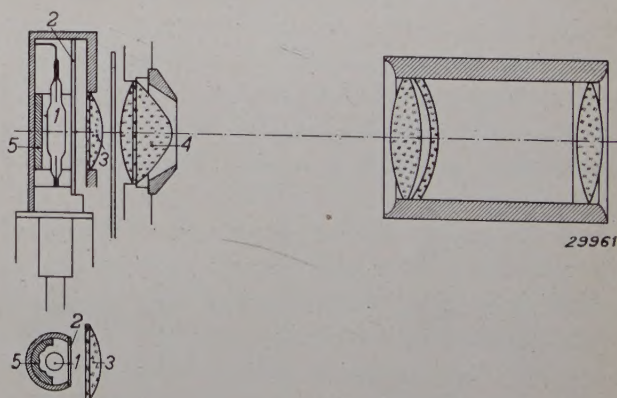
The arrangement ordinarily used for lantern slides, that of *fig. 2b*, is therefore much more satisfactory for mercury lamps, and actually forms the basis of the construction of the new installation for film reproduction.

Fig. 3 gives a cross section and view from above of the optical system.

The mercury lamp 1 is in a metal boat which is shown separately in *fig. 4*. This boat is placed in a tube (see *fig. 5*) through which the cooling water flows. The boat is closed by a plane glass 2 . In front of this is a planoconvex lens 3 which receives the light from the mercury lamp over an angle of divergence of about 90° .

This lens has a relatively small refraction because one surface is bounded by water instead of air. Therefore a second condenser lens (4) must be used. Between the two lenses (3 and 4) space is left for the rotating sector.

The light which the lamp emits in the backward direction is directed forward by a cylindrical mirror 5 .



29961

Fig. 3. Cross section of the optical system for the illumination of the film by means of a water-cooled mercury lamp. 1 mercury lamp, 2 glass plate, 3 and 4 lenses of the condenser, 5 rear mirror.

It is desirable to concentrate as much light as possible in the neighbourhood of the light source. A certain lateral deviation is, however, necessary because, due to the strong refraction of the quartz,

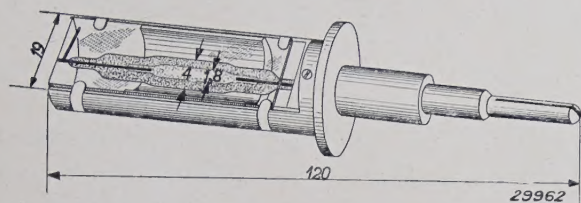


Fig. 4. The boat with the mercury lamp. The numbers give the chief dimensions in mm. The projecting pin on the right is one of the electrical connections, the other is formed by the container of the boat. The cooling-water flows in on the left and out through a hole in the rear wall. The boat is closed by a glass plate.

it is impossible to send light through the free space between the constricted discharge and the inner wall of the mercury tube.

The action of the rear mirror may be seen in *fig. 6*. If the path of the rays is examined in a transverse cross section, four images are seen to appear beside the discharge, which together form a lighted surface about 8 mm wide. In the longitudinal cross section there is no focussing, but this is unnecessary because, due to the oblong form of the source, the beams have a sufficiently great angle of divergence in the longitudinal cross section.

The direct and reflected light of the mercury lamp must now be used to illuminate the film uniformly. A gradual variation of brightness, namely a decay of brightness toward the edges of the film, is by itself not a great objection since the eye is also only slightly sensitive to differences in bright-

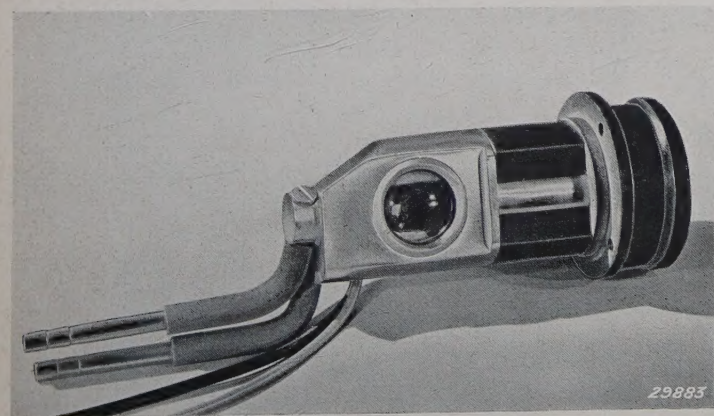


Fig. 5. The tube which contains the boat for the mercury lamp. The boat is slid in from the right and fixed in position with a hollow screw in such a way that the flange forms a watertight closing. Afterwards the large cover is set on the tube from the right. The electrical contact is first made through this cover between the positive terminal of the supply voltage and the pin of the boat. During assembly or demounting, therefore, the lamp can never be under tension.

ness. The eye is, however, very sensitive to small changes in the spectral composition of the light. Since the condenser is not completely achromatic, so that the light of the blue mercury line is distributed over the film in a somewhat different way from the green mercury line, very disturbing colour differences might occur if there were a slight irregularity in the illumination of the film.

When such differences in colour are observed, it has been found sufficient to place a frosted glass plate between the source and the condenser. The spreading of the light by this plate is only slight, because it is immersed in water, *i.e.* in a medium with practically the same index of refraction. Nevertheless this scattering is enough to make the illumination of the film absolutely uniform.

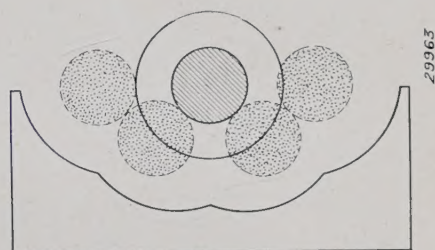


Fig. 6. The action of the rear mirror. In the transverse cross section of the light source four images of the radiating column appear beside the source, so that directly in front of the condenser a high concentration of light is attained.

Light production and colour

The light flux which is directed on the screen is practically the same as that of a carbon arc of 45 A, and, with the sector rotating and without film, it is about 2 500 lumens. The light is bluish-white in colour and resembles that of the so-called "high-intensity" arc.

The spectrum of the light of the mercury lamp is, as is well known, not continuous, but consists of a number of lines, chiefly a green one, a yellow one and several blue ones. However, thanks to the high pressure to which the mercury vapour is subjected, a continuous background³⁾ appears between the lines, so that with increasing loading of the mercury lamp the spectrum begins more and more to resemble that of an incandescent body.

The spectral composition is of particular importance when colour films are shown. In that case it is not enough to require

³⁾ In this connection see the articles: Comparison between discharge phenomena in sodium and mercury vapour lamps, Philips techn. Rev. 1, 2, 1936; The Mercury Vapour Lamp HP 300, Philips techn. Rev. 1, 129, 1936; Watercooled Mercury Lamps, Philips techn. Rev. 2, 165, 1937.

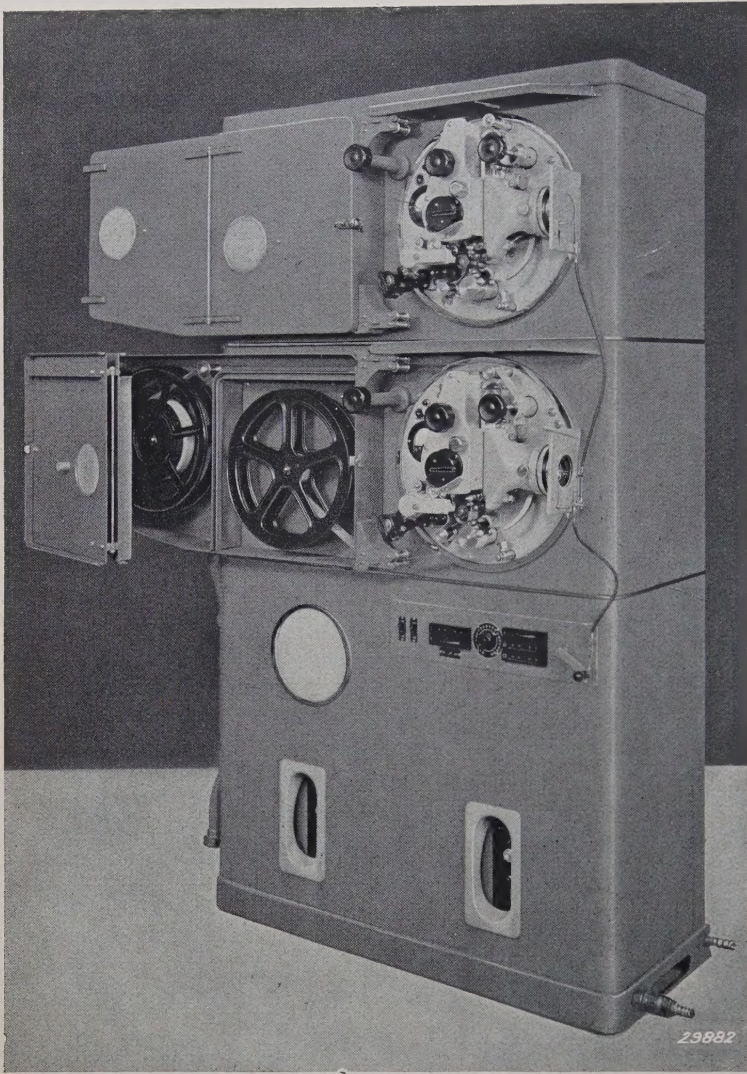


Fig. 7. The Philips double film reproduction installation FP2. It consists of two projectors one above the other. The lower cabinet contains the amplifiers, the supply apparatus and the cabin loud speaker. The two projectors are housed together with the necessary arrangements for sound scanning; behind each projector there are two film drums.

that the light source should be "white", but the additional requirement must be made that the light must have about the same relative distribution in the various wave length regions as daylight.

In *table II* the distribution is indicated of the light flux of the mercury lamp for cinema projection over different sections of the wave length scale, and compared with that of various other sources of white light. The choice of the sections is adapted to the properties of the eye⁴⁾ in a way which was discussed previously in this periodical.

It may be seen from the table that the radiation of the mercury lamp is quite similar to that of daylight in the middle sections (3 to 6). In the blue sections 1 and 2 the intensity is about twice as high. This excess of light can be absorbed by a yellow filter. The highest relative deviations appear, however, in the red sections 7 and 8 where the intensity of the mercury lamp is only $\frac{1}{3}$ of that of daylight.

The intensity of the red radiation can be increased by using red-transmitting sectors instead of opaque ones in the rotating sector disk. A further increase of the intensity in the red is possible by increasing the specific loading of the mercury lamp.

⁴⁾ See the articles: Colour Reproduction in the Use of Different Sources of "White" Light, Philips techn. Rev. 2, 1, 1937.

Table II

Relative light flux (% of the total light flux) which is radiated in different sections of the wave length scale.

Section (Å)	4 000 - 4 200	4 200 - 4 400	4 400 - 4 600	4 600 - 5 100	5 100 - 5 600	5 600 - 6 100	6 100 - 6 600	6 600 - 7 200
Light source	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Electric lamp	0.005	0.058	0.25	5.4	33.5	42.7	16.6	1.54
Carbon arc	0.013	0.116	0.43	7.4	37.3	40.0	13.6	1.13
Sunlight	0.016	0.175	0.64	9.2	39.3	38.2	11.6	0.91
Daylight	0.025	0.26	0.91	11.1	40.8	36.2	9.9	0.73
High intensity arc	0.050	0.27	0.97	10.2	43.7	33.2	10.6	0.94
High pressure mercury lamp for film projection	0.042	0.53	0.87	4.6	52.6	37.6	3.4	0.25
More highly loaded mercury lamp with red sector and yellow filter	0.03	0.4	0.9	4.4	50	37	6.8	0.5

Experiments have shown that upon application of these measures a satisfactory colour reproduction is possible. The last line in Table II gives the spectral distribution of a mercury lamp with increased load provided with a red rotating sector and a yellow filter.

The energy consumed by the mercury lamp (with rectifier) is 1.5 kW. In the case of a carbon arc of 45A the total consumption is about 3 kW so that a saving of 50 per cent is achieved. Because of this the heat development of the mercury lamp is much less, and moreover about 90 per cent of the heat radiation is removed by the cooling water.

Fig. 8. Rear view of the film reproduction installations (opened). In the middle of either cabinet is the motor for moving the film. To the left of the motor the projection arrangement may be seen mounted in a ring. Behind the motor are the two tubes which conduct the cooling water to the jacket of the mercury lamp. The screened cable may also be seen which connects the photocell for sound scanning to the photocell amplifier in the upper left-hand corner of each projection cabinet.

Fig. 9. The projection arrangement for lantern slides, mounted on the back of the upper projector cabinet. It consists of two light sources (mercury lamp, extreme right), each with its condenser and projection lens (to the left, movable along the bars). The two systems work alternately. Upon changing from one slide to another the beam of light of one system is gradually cut off by a lever switch (on the middle bar) with the help of a diaphragm set up behind each objective, while at the same time the beam of the other system is raised to full strength.

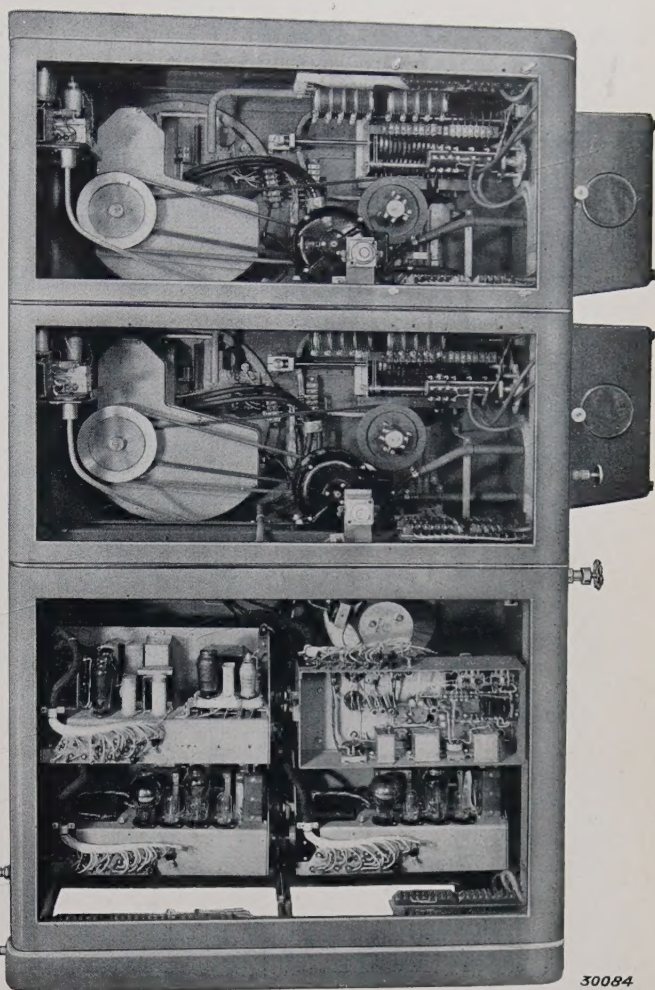


Fig. 8

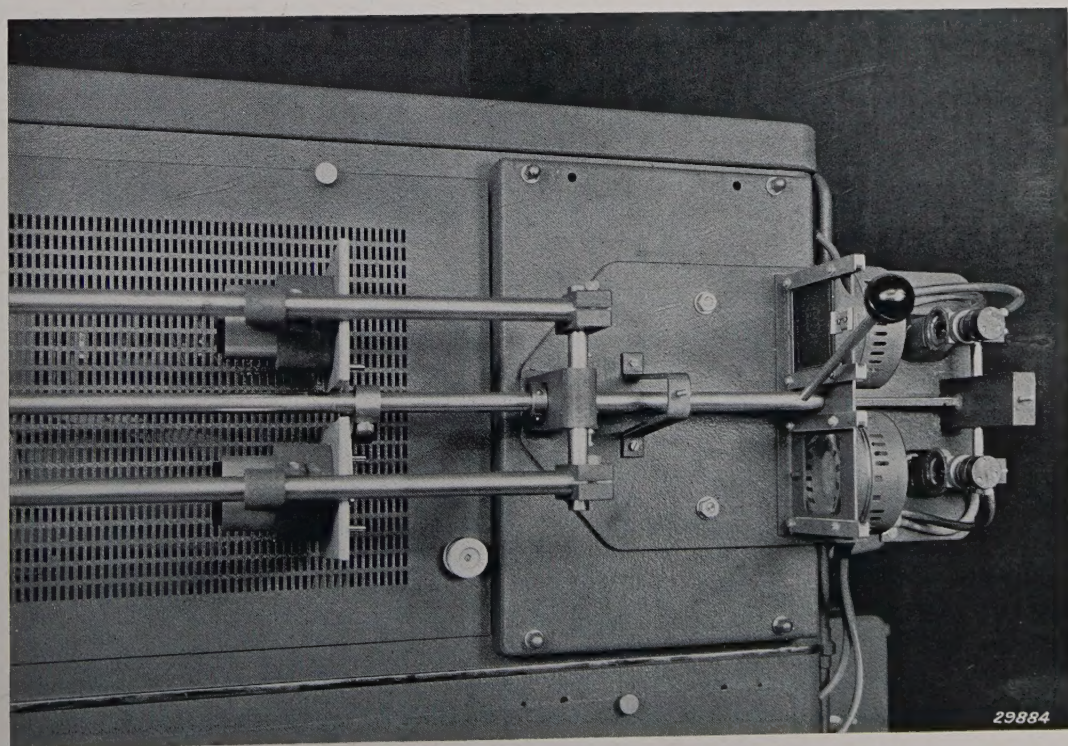


Fig. 9

The arrangement of the whole installation

Following the foregoing explanation of the optical system we shall consider the installation for film reproduction as a whole. *Fig. 7* is a photograph of the apparatus. The compact structure which was made possible by the very small dimensions of the light source is immediately striking.

The lamp forms as it were a unit with the film window. At the spot where the arc lamp ordinarily

In each of the projector cabinets there is the optical system with the necessary water-cooling, and further the scanning apparatus for the sound track with the first stage of the necessary amplification. In the cabinet also is the mechanical arrangement for moving the film across the optical system and the "sound head".

In the cabinet below are the amplifiers and the supply apparatus. *Fig. 8* is a photograph of the

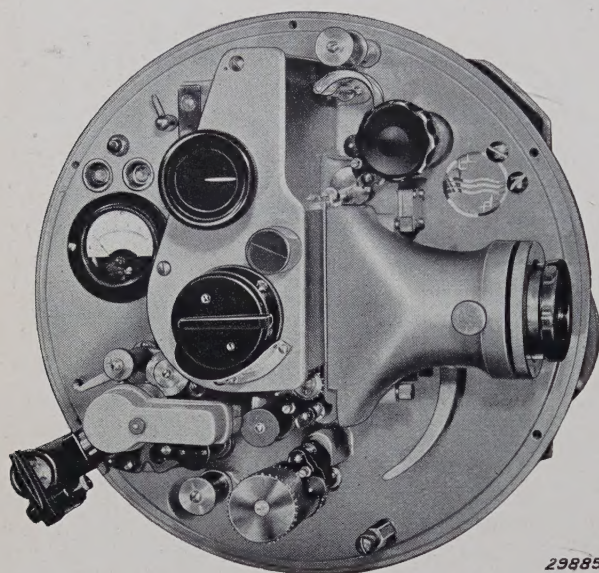
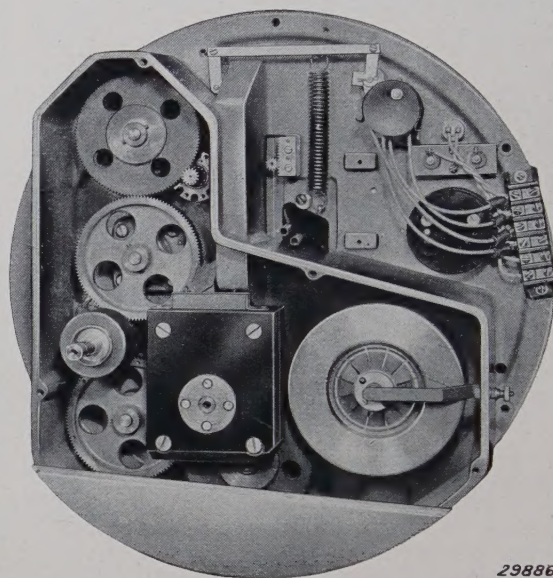


Fig. 10. Front and rear side of the projector. The whole mechanism (mercury lamp and lenses) can be moved in a vertical direction by means of the knob with the white line. In this way the position of the film window can be so adjusted, that in the positions of rest of the rotating sector it corresponds exactly with the position of one film picture (framing). The knob in the middle of the figure is that of a revolving head which contains two mercury lamps. By giving this knob a half turn the lamps can be interchanged. At the same time the connections for electric current and cooling water are switched over to the lamp put into use. The knob in the upper left-hand corner serves to switch on the apparatus. The switching on takes place in four steps:

- 1) Switching on of motor and primary winding of transformer.

stands are the film drums. This arrangement has made it possible to mount one above the other the two projectors which are necessary in order to be able to change the reels of film without interrupting the performance. This means a great saving of space.

In order to align the projectors in the vertical plane they are mounted in a ring as may be seen in the photograph so that they can be turned about a horizontal axis. In the horizontal plane the projector cabinet which contains the ring can itself be turned a few degrees.

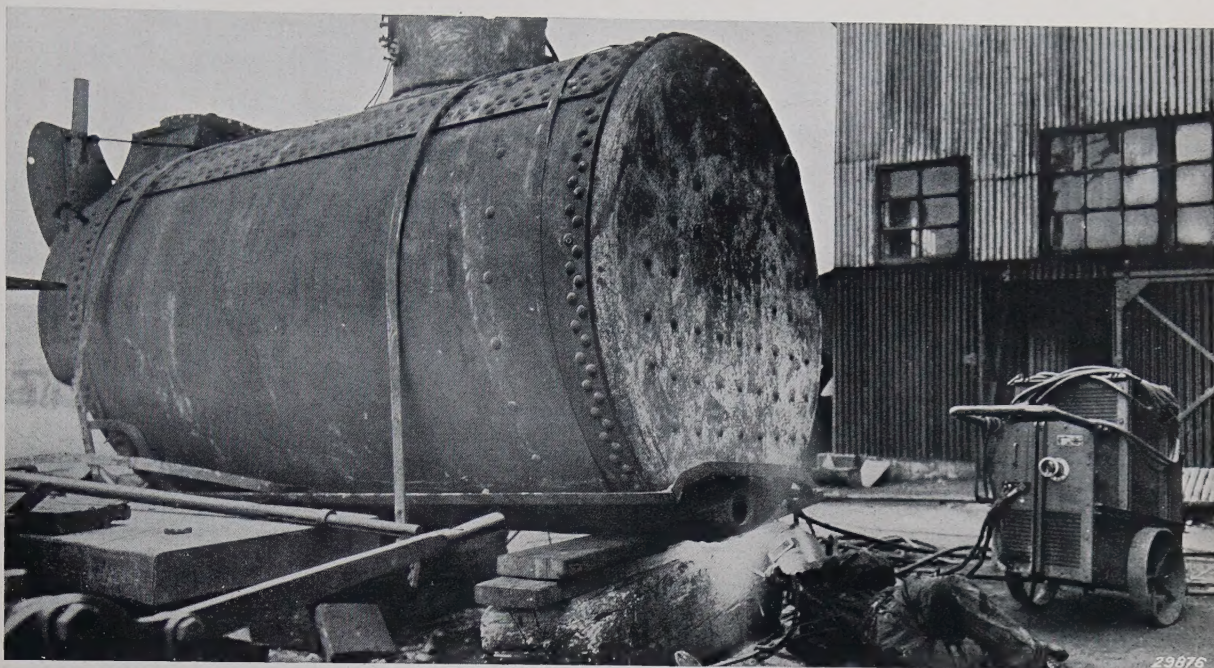


- 2) Motor brought up to normal number of revolutions.
- 3) Ignition of the lamp.
- 4) Current in lamp raised to normal working strength.

The lamp current can be read off from the ammeter. In the lower left-hand corner is the system for sound scanning. Below to the extreme left is the exciter lamp. Diagonally upward follow: a condenser, a slit, a reversed microscope lens which focusses a reduced image of the slit on the sound track, and a photocell contained in the grey box. In the photograph of the rear side may be seen the heavy fly-wheel which serves to keep the motion of the film through the sound-scanning apparatus absolutely uniform. To the left of the fly-wheel is the rotating sector inside the square container. The rotating sector turns in oil which is kept clean by means of magnetic filters. The magnetic filter has been described previously in this periodical (see *Philips techn. Rev.* 2, 297, 1937).

apparatus taken from the rear. The covers of the cabinets have been removed so that the interior may be seen.

On the cover of the upper projector cabinet the arrangement for projecting lantern slides is mounted (see *fig. 9*). Here also mercury lamps of the type described in this article are used. *Fig. 10* gives pictures of several details of the mechanism of the projector, which are described in more detail in the text under the figure.



OVERHEAD WELDING

by J. SACK.

621.791.052

In this article a study is made of the forces acting during the transfer of weld metal from the welding rod to the piece of work in overhead welding. In this case the transfer of welding material is opposed by the weight of the drops, the kinetic pressure of the electrons in the arc and the electrodynamic forces on the charged drops due to the convergence of the current lines of force at the crater. On the other hand the transfer is promoted by capillary forces, electrodynamic forces due to the constriction of the liquid metal as the drops leave the rod and explosive forces. From an estimation of these forces it is clear that overhead welding is possible, as experience has in any case proved.

Introduction

In arc welding use is made of welding rods which are melted by the heat developed by an electric arc between welding rod and piece of work. Welding is usually done in such a position that the piece of work is below the welding rod, this is called horizontal welding. But it is sometimes necessary to carry out the welding operation from below, on the under side of the object to be welded. The operator must of course stand in such a position that he can easily see the arc and the pool (the area of molten metal on the article being welded). The work is then above his head, and the process is called overhead welding. Experience has shown that this work can easily be performed with suitable welding rods such as the type PH 50.

It is known that the metal is transferred from the welding rod to the weld in the form of larger or smaller drops¹⁾, which, in the case of overhead welding, means that the force of gravity is overcome. In overhead welding it is clear that there are other

forces besides that of gravity acting on the drops, and the question naturally arises as to the nature of these forces. The explanations which have been proposed are vague or inadequate. Only with the help of X-ray cinematography²⁾ have we been successful in obtaining a clear picture of what occurs in overhead welding.

A survey and an estimation of the intensity of the forces which act during the formation and transfer of a drop are given below. Some of these forces oppose the transfer of drops and will be called opposing forces. They must be overcome by the forces which we shall call the propelling forces.

Opposing forces

Force of gravity

The weight of the drops can be determined by moving the rod in such a way that the drops fall separately and can be weighed. For the sake of

¹⁾ J. Sack, Philips techn. Rev. 2, 129, 1937.

²⁾ J. Sack, Philips techn. Rev. 1, 26, 1936.

simplicity this is done in horizontal welding. Separate drops are obtained by moving the welding rod sufficiently rapidly over the work (a flat plate for example)²⁾. If a welding rod with an iron core is used — and we shall deal only with that kind in this article — and a plate not of iron but of copper, the drops do not stick to the plate, but can be removed and weighed.

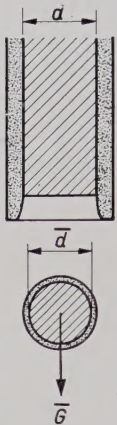
Fig. 1. shows graphically the result of this experiment. It may be seen from the graph that 2.3 g of the rod were melted into drops whose weight varied from 120 to 140 mg. As average weight is taken the weight determined by the abscissa of the densest part of the diagram, and in the case of fig. 1 this is:

$\bar{G} = 148 \text{ mg}$

In table I are given the average weights together with the average dimensions of drops obtained with welding rods of the types PH-50 and PH-48 having different core diameters d . Type PH-50, with an inorganic coating, gives a drop with an average diameter of $0.7 d$. This drop is considerably smaller than that of type PH-48 with a partially organic

coating, which gave an average diameter of drop of $0.9 d$. A difference in size of drop is manifested in a difference in welding properties, and the oper-

Table I



TYPE	d	I	\bar{G}	\bar{d}	\bar{d}/d	
PH 50	mm	amp	mg	mm		0,69
	5	220	150	3,3	0,66	
	5	190	190	3,6	0,72	
	3 1/4	116	50	2,3	0,71	
	3 1/4	116	40	2,15	0,66	
	2 1/2		22	1,75	0,70	
PH 48	4	111	196	3,6	0,90	0,89
	4	131	214	3,7	0,93	
	4	143	148	3,3	0,83	

29874

ator will immediately classify the welding rod PH-48 as a coarse-drop rod, and the rod PH-50 as a fine-drop or “spraying” rod. In overhead welding it is important to have the weight of the drop small; in this respect a rod of the type PH-50 is to be preferred.

Other opposing forces

In order to find out whether other forces besides that of gravity act on the drop, the action of gravity may be excluded by welding on a vertical plate with the rod held in a horizontal position. It is then observed that when the arc burns, and before any drops are transferred, there is a force acting which pushes the welding rod away from the plate and which is dependent upon the current strength.

The value of this force may vary somewhat for different types of welding rods, and it sometimes also depends upon the polarity. Under normal working conditions the force is about 1 g for welding rods of 4 mm and about 2 g for those of 6 mm, thus many times greater than the weight of the drop. The relation between this pressure force and the current may be represented approximately by the equation:

$K = 0.05 I^2 \text{ (dyne)}$

where I is the current in amperes³⁾.

The pressure force on the liquid drop of the welding rod forms a depression in the drop which is al-

³⁾ This formula is deduced from measurements by F. Nieburg, Elektroschweißung 9, 101, 127, 1938. Similar, somewhat less accurate, results were obtained previously by F. Creedy, R. O. Lerch, P. W. Seal, and G. P. Gordon, A.I.E.E. Paper No. 32 - 41, Abstract Electr. Eng. 51, 49, 1932. Both estimations referred only to the force of pressure several seconds or fractions of seconds after the ignition of the arc. The variations in the force during welding were not determined.

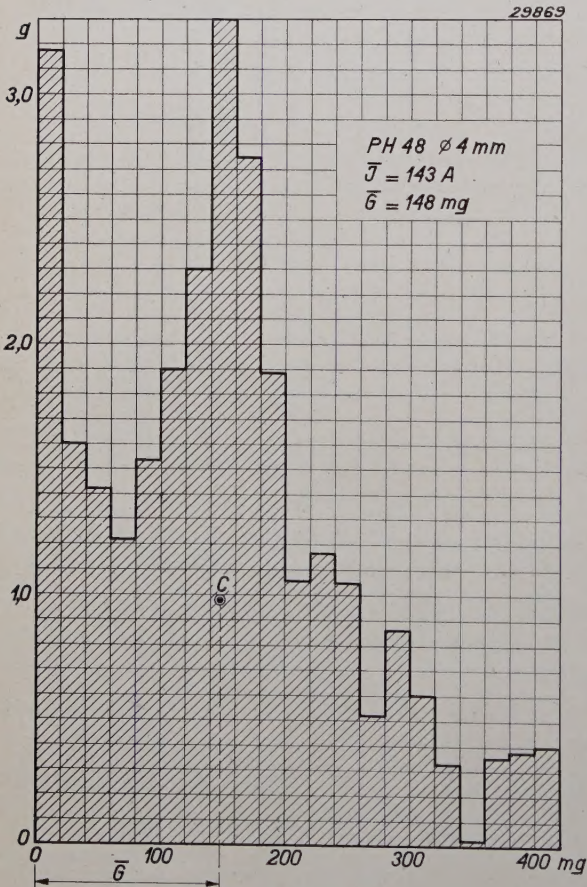


Fig. 1. Graph showing the size of the drops in welding. The ordinate shows how much material (in grams) was transferred in the form of drops of a weight given by the corresponding interval on the abscissa axis.

ways observed in X-ray cinematographic pictures (see for instance *fig. 2c*).

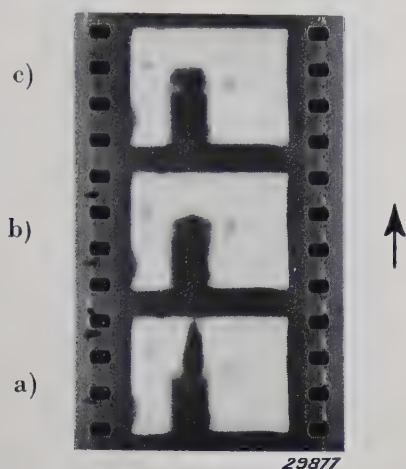


Fig. 2. X-ray cinematographic film (50 pictures per sec) of the drop in overhead welding. The stretchedout form of the drop in picture *a* and the depression on the top of the drop in *c* should be noticed especially.

The present state of knowledge about the welding arc is inadequate to give perfect insight into the causes of this opposing force. Physicists are most interested in what happens at the cathode of the discharge, and the pressure has been theoretically examined at the cathode⁴). From the calculation it is found that the repelling force may be mainly ascribed to the bombardment of the cathode by positive ions. If n is the number of ions (or electrons) per unit volume of the column of the arc, the pressure of the ions on the cathode is

$$p = n k T, \quad \dots \quad (1)$$

where T is the absolute temperature of the electrons and k is Boltzmann's constant.

In the welding arc the temperature of the electrons as well as that of the ions is about 6 000 °K, while the concentration of electrons may be estimated at $n = 2 \cdot 10^{16}$ electrons per cubic centimetre⁵). Using these values in equation (1) a pressure is obtained of $p = 17\,000$ dynes/sq.cm.

The size of the cathode spot on which the pressure

⁴) L. Tonks, Phys. Rev. **46**, 278, 1934.

⁵) This estimation is based on the assumption that there exists an ionization equilibrium between the electrons and the iron vapour in the arc. The degree of ionization α of the iron can be calculated by means of Saha's formula which is as follows:

$$\lg \frac{\alpha^2 P}{1-\alpha^2} = -\frac{5000}{T} V_i + 2.1 \lg T - 6.5.$$

P is here the pressure of the iron vapour, in our case 1 atmosphere. V_i is the ionization potential of the iron atoms and is equal to 7.8 volts. The degree of ionization α is small compared with unity. If the relation between the gas density and the temperature is taken into account, the

acts, follows from the current density at the cathode, which is about 7 000 A/sq.cm. With a current of 180 A the area of the cathode spot is $f = 180/7\,000 = 0.026$ sq.cm, and the force on the cathode thus becomes:

$$k = pf = 17\,000 \cdot 0.026 = 440 \text{ dynes} = 0.435 \text{ g},$$

while the observations under these circumstances give an average value more than twice as great.

Finally the electrodynamic forces must be taken into account, which are due to the action of the electro-magnetic field on the lines of force of the current. The electric current through a conductor may be considered to be flowing through tubes of current which attract each other since the direction of the current is the same in all the tubes.

If the top of a welding rod is examined in the initial state, *i.e.* before any drop has been formed- (see *fig. 3*), it will be seen that the current lines

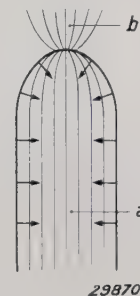


Fig. 3. Current lines of force at the top of the welding rod. The arrows indicate the direction of the electrodynamic forces. The convergence of the current lines gives rise to a resultant downward force.

converge at the crater. The electrodynamic forces, which are also represented in *fig. 3*, have a downward resultant due to the curve in the lines of force of the current. The value of the resultant force can be calculated (see p. 14) and we find:

$$k = \frac{I^2}{200} \ln \frac{O_2}{O_1} \text{ dyne}, \quad \dots \quad (2)$$

where O_1 is the area of the crater and O_2 the cross section area of the iron core of the welding rod, while I must be in amperes. For $I = 180$ A and a negative crater (0.026 sq.cm) one finds $k = 255$ dynes = 0.26 g.

If the crater is positive then its area is so large that one may hardly speak of a convergence of the lines of force. In this case therefore the electrodynamic force may be neglected.

following is found for the number of electrons per cc:

$$n = 4.3 \cdot 10^{18} \sqrt{\frac{4}{T}} \cdot 10^{-\frac{2500}{T} V_i},$$

and for $T = 6\,000$ °K and $V_i = 7.8$ volts it follows that $n = 2 \cdot 10^{16}$.

Propelling forces

We noted above that the resultant opposing force at the beginning of drop formation is many times greater than the weight of the drops. The propelling forces must be able to overcome these forces, since otherwise the transfer of drops would be impossible in overhead welding.

The most important propelling forces are the surface tension, the electrodynamic and explosive forces.

Surface tension

Capillary force or surface tension already plays an important part during the formation of the drops. It is due to this force that the liquid metal remains on the top of the welding rod and does not run along the rod and drip off. Surface tension also keeps the molten metal in the inverted pool.

When the arc is kept short enough the drop on the welding rod can make contact with the pool, which can then absorb part of the drop of liquid metal. *Figs. 4a, b, c* and the X-ray photographs

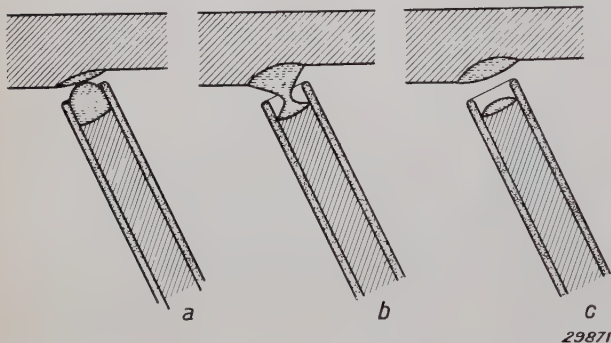


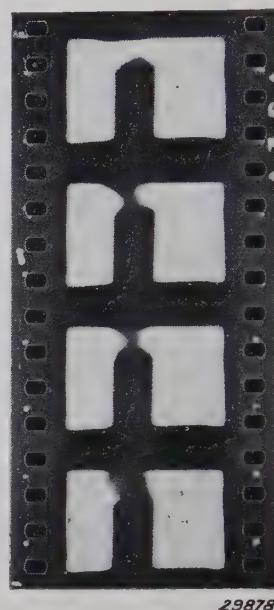
Fig. 4. Transfer of liquid material from the welding rod to the piece of work.

fig. 5 show the three stages of this process:

- The molten metal of the piece of work makes contact with that on the welding rod.
- The drop of metal between the work and the welding rod becomes attenuated and finally splits into two parts.
- The division is complete; the pool has become larger, the drop smaller. Material has therefore been transferred *from* the welding *to* the piece of work. For this transfer of material the pool must not be too large at the beginning of the process. This requirement will not be fulfilled in overhead welding if the current is too high or the piece of work too hot. In the latter cases the liquid metal falls out of the pool and instead of welding, a hole is burned in the work.

The manner of material transfer just described is of particular importance when bare welding rods are used, since with bare rods it is impossible to

weld except with a short arc. With an arc which is too long the liquid metal simply drips from the welding rod.



29878

Fig. 5. X-ray photograph of the transfer of material from a thinly coated welding rod to the piece of work in the manner indicated in *fig. 3*.

Electrodynamic forces

The arc is usually kept as short as possible in welding. In overhead welding with bare welding rods this is — as we have just seen — absolutely necessary. But with thickly coated welding rods it is also possible to work with a longer arc, and in this case the material transfer takes place in quite a different way as can be seen from the X-ray photographs (*fig. 6*). The molten metal on the top of the welding rod breaks away usually in the form of a spherical drop which is thrown upwards with a fairly great speed. If the distance from the welding rod to the work is too great the drop thus shot upward will not reach the piece of work, but will fall to the ground along a more or less parabolic path.

The drop formation of the molten metal of the welding rod may be explained as follows. As was represented in *fig. 3* the mutual attraction of the current lines of force causes radial forces in the rod. These forces are generally too small to cause a deformation of a solid conductor. They may, however, with a sufficiently high current, be great enough to cause changes of form in a fluid conductor. This was first noticed and investigated theoretically in connection with induction smelting furnaces⁶⁾ in which iron is heated and fused by induction in a horizontal ring-shaped gutter. The smelt forms

⁶⁾ E. F. Northrup, *Phys. Rev.*, **24**, 474, 1907.

a ring-shaped fluid conductor in which constrictions appear under certain circumstances. How will

graphic pictures: fig. 2a shows a stretched drop and fig. 8 a flattened one.

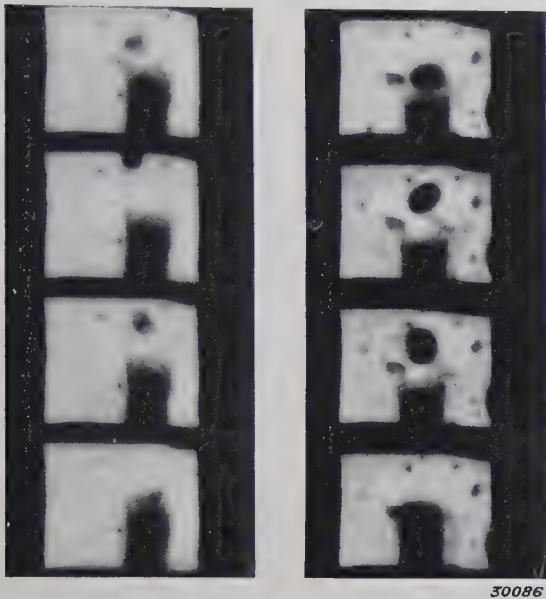


Fig. 6. X-ray photograph of the transfer of drops between welding rod and work. The arc is very long. In contrast to fig. 4 where the drops touch the piece of work and then let loose from the welding rod, the drops are in this case “shot away” from the welding rod.

this effect, which is called the pinch effect be manifested in the case of the drops from welding rods?

When there is a large enough quantity of liquid material on the top of the welding rod, a constriction will occur with coated welding rods as is shown in fig. 7a. The current lines of force no longer run parallel to the axis of the rod, and as a result the pressure force is given an axial component. When for some reason or other the drop is flattened (fig. 7b) or stretched (fig. 7c) the electrodynamic forces will reinforce the deformation, and very much deformed drops can occur in this way. Such drops can sometimes be observed in the cinemato-

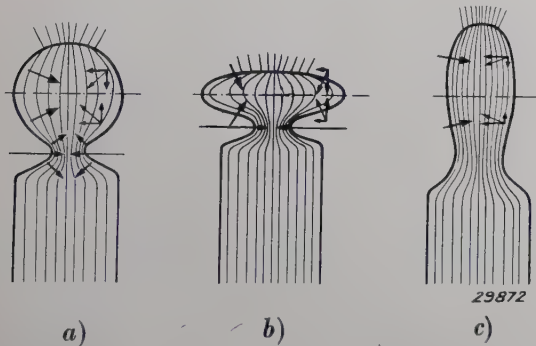


Fig. 7. Current lines in the welding rod and drop. The arrows indicate the direction of the electrodynamic forces. It may be seen that the forces have the tendency to constrict the neck of the drop and to tear it loose from the welding rod. From figs. b and c it may be seen that the forces act to make a flattened drop still flatter and a stretched drop still longer.



Fig. 8. A drop temporarily very much flattened by electrodynamic forces.

In general the constriction of the neck becomes steadily greater until the drop is quite free. The constriction is due partly to surface tension, but may be ascribed mainly to the above-discussed electrodynamic forces, as may be seen from fig. 7 where the liquid metal is shown to be torn apart at the place where the constriction occurs.

As the neck of the drop becomes smaller the upward component of the electrodynamic force becomes greater. Calculations, which will be given briefly below, show that the electrodynamic force on a piece of a conductor is always directed from the smaller to the larger cross section, and therefore in this case upwards, when the cross section of the neck is smaller than the area of the crater.

The area of a negative crater of an arc usually only amounts to several square millimetres, while the area of the positive crater is the same as that of the cross section of the drop. An upwardly directed electrodynamic force will therefore mainly occur when the welding rod is connected to the positive terminal. When the neck of the drop has been sufficiently constricted the force becomes greater than the force of gravity acting on the drop (and other opposing forces), with the result that the drop leaves the welding rod with some speed.

This is also shown in the film reproductions in fig. 6. In these cases the path of the drop could be followed in several pictures, and the initial velocity

Table II

$\phi = 4\text{ mm}$ $J = 140\text{ A}$

m	V_0	S	T
mg	cm/sec	$dyne\ sec$	erg
72	32	2,3	37
62	16	1,0	8
157	17	2,7	23
		$\bar{S} = 2,0$	$\bar{T} = 23$

$S = \int K dt$

A diagram showing a cross-section of a drop on a rod. An upward arrow labeled 'S' represents the electrodynamic force, and a downward arrow labeled 'mg' represents the gravitational force. Below the diagram is a '+' sign.

29875

of the drop could be estimated from it. If one assumes that only the force of gravity acts on the free drop, the initial velocities given in *table II* are obtained from the sections of film which can be used for the determination. The drop is thus "shot" away with an average impulse of 2 dynes/sec, or an average kinetic energy of 23 ergs.

A theoretical estimation of the electrodynamic forces leads to the same order of magnitude. If one calculates for a solid of revolution as in *fig. 9* the electrodynamic force which acts

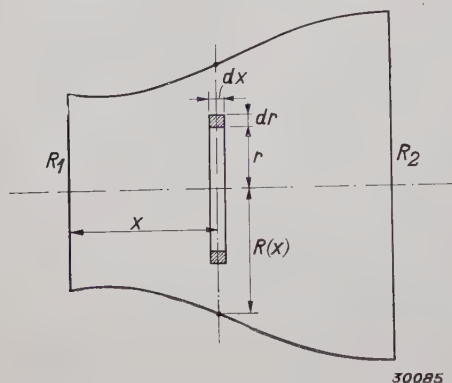


Fig. 9. Sketch for the purpose of calculating the electrodynamic forces acting on a piece of a solid of revolution.

on a ring-shaped element of volume (position x , radius r), a resultant force in the x direction is found of the magnitude:

$$dK_x = I^2 \cdot \frac{4}{100} \frac{r^3}{R^5} \cdot \frac{dR}{dx} dx dr \text{ (dynes),}$$

in which R is the radius of the body at the point x and I is the current in amperes. This formula is valid under the assumption that R changes only slowly with x ⁷⁾.

The total force on the body is obtained by integrating the above expression with respect to r (from 0 to R) and to x (from x_1 to x_2). The following is the result:

$$K_x = \frac{I^2}{100} \ln \frac{R_2}{R_1} = \frac{I^2}{200} \ln \frac{O_2}{O_1}.$$

It may be seen from this formula that the force depends upon the current and the cross sections at the beginning and of the piece of conductor considered, and that it is always directed from the smaller to the larger area.

If this result is applied to the molten drops, the area of the crater must be used for O_2 and the cross section of the neck for O_1 .

The force K_x becomes a propelling force the moment the cross section of the neck becomes smaller than the crater. Upon further constriction, at a certain radius R_1 of the neck, the upward electrodynamic force will be equal to the weight G of the drop. From that moment the drop will begin an upward movement, and as a consequence the constriction will be accelerated.

In order to calculate the total energy which is transferred to the drop we must know the length of the path over which the electrodynamic forces act until the drop is quite free.

This path will be of about the same order as the radius R_1 of the neck. We shall make this supposition more definite by assuming that in the upward motion the radius of the neck decreases at the same rate as the drop moves upward. With this assumption we find for the total kinetic energy T which is given to the drop up to the moment when it is freed:

$$T = \frac{I^2}{100} \cdot R_1.$$

Let us examine particularly the experiments whose results are given in *table II* for the case of a welding rod with a core diameter d of 4 mm, a drop of $0.7 d = 2.8$ mm diameter and a direct current of 140 A. The current density at the crater determines the area of the latter and at the same time also the magnitude of the upward electrodynamic force. If the current density is considered to be 7000 A/sq.cm for the cathode spot and 1400 A/sq.cm for the anode spot, one finds, according as the welding rod is positive or negative, values for R_1 of 0.09 and 0.05 cm respectively, and for T , 18 and 10 ergs respectively. Under the conditions of the observations of *table 2*, i.e. positive polarity, the energy of 18 ergs taken up by the drop is in good agreement with the observed average of 23 ergs.

Explosive forces

In the following attention will be concentrated on the phenomena occurring in the neck of the drop. Due to the electrodynamic forces the neck is continually narrowed, but since the electrical conductivity of liquid iron is much greater than that of the molten coating, the electric current will continue to flow chiefly through the ever narrowing neck. The heat developed by the electric current will increase the temperature of the neck until the boiling point of iron has been reached.

Since the whole process is completed in several tenths of a millisecond, as will appear from the discussion below, it is understandable that a merely slight delay in boiling can lead to a considerable exceeding of the boiling point, whereupon the neck passes into the vapour form explosively. A temporary over-pressure then occurs which can shoot the drop away with considerable speed, especially when the space between the drop and the rod is partly closed by molten flux so that the gases cannot immediately escape. This is always so in the case of coating welding rods. A similar phenomenon may occur due to the fact that the iron contains dissolved gases which are probably driven out of the iron before it reaches its normal boiling point. We may then expect that a bubble of gas will be formed inside the neck, a fact which has actually been observed several times by means of photographs (*fig. 10*).

The increase of temperature due to the electric current through the ever narrowing neck can easily be calculated if one assumes that heat dissipation does not occur; this will only be true in the case of a very narrow neck such as may occur imme-

⁷⁾ In this case it may be assumed that the axial component of the current density is equal at all points of a plane cross section perpendicular to the axis.

diately before the explosion. The diameter of the neck can be estimated from observations of the variation of voltage by means of a cathode ray oscillograph. It will be seen that every transfer of a drop is accompanied by a voltage peak of about 20 volts on the average with a welding current of 140 A. The duration of this peak is of the order of $2 \cdot 10^{-4}$ sec.



29881

Fig. 10. Preparation for an explosion. A vapour or gas bubble is formed in the interior of the neck.

This voltage peak may be ascribed chiefly to the electrical resistance of the neck which can be calculated from it and is found to amount to 0.14 ohm. If the neck is considered to be a cylinder 1 mm in height (in agreement with the photographs) the

area of the cross section is found to be $3.6 \cdot 10^{-4}$ sq.cm.

The time which would be necessary to vaporize this neck completely would be $6 \cdot 10^{-4}$ sec at the given voltage and current. It is reasonable to assume that the actual lifetime is only a fraction of this time (in agreement with the observed value of $2 \cdot 10^{-4}$ sec), because during the vaporization the narrowing of the neck continues and, moreover, the speed of evaporation is thereby increased.

The fall in voltage in the neck during the transfer of the drop does not occur only in overhead welding but also in other positions. This voltage drop is in series with the arc voltage and may, if the available voltage is too low, lead to the extinction of the arc. In welding with a welding transformer it has been found that the phenomenon of extinction of the arc occurs at a no-load voltage of the machine which is too low, and that it occurs often the lower the no-load voltage. For this reason transformers which have too low a no-load voltage (less than 50 volts for example) cannot be considered suitable as welding transformers.

ILLUMINATION AND BLACK-OUTS

by P. J. BOUMA.

628.97 : 355.585

From a study of physiological data the brightnesses and intensities of illumination are deduced which under various circumstances are permissible in times of danger from air-raid. General principles are given for the illumination at such times. It is shown how the Philips "Protector" lamps provide a solution of the problem. In conclusion the influence of the colour of the light is briefly discussed.

The problem of planning a satisfactory outdoor illumination under normal conditions has already been discussed in this periodical from a number of different points of view. The problem takes on quite a different character when it is studied in connection with a possible danger of air-raids in time of war.

The primary requirement made of the illumination is that it must not enable the aviators to orient themselves or observe the position of cities, buildings, etc. There is then also the secondary requirement that on the ground there should be high enough visibility so that traffic is still possible, although with very much reduced speeds.

In the following the conditions will be studied on the basis of physiological optical data for satisfying the primary requirement of "non-visibility from the air", and the way in which these conditions can be realized in practice while retaining the best possible visibility on the ground.

Physiological optical basis

Accurate information about visibility of light

spots of different sizes and brightness under the conditions which hold for the observer in an aeroplane during an air-raid can only be obtained by experiments on a large scale made by aviators from the air. Even then it will still be very hard to imitate actual conditions accurately. The observer will in the tests usually fly over well-known country, the psychological factor is also quite different from that during an air-raid, etc. All such factors may exert an influence on the result which should not be underestimated.

Since we possess no reliable results of such practical observations, we shall try to obtain the necessary numerical data in quite a different way. We shall begin with the large amount of observational material which has been collected in numerous laboratories on the visibility of objects of different size and brightness. Practical experience has, however, shown that under laboratory conditions much lower threshold values are obtained than under practically occurring conditions. In order to solve this problem we shall make use of the

experience gained in navigation in the observation of light signals.

The most important laboratory data upon which we base our considerations will be found reproduced in fig. 1. In this figure the minimum intensity of

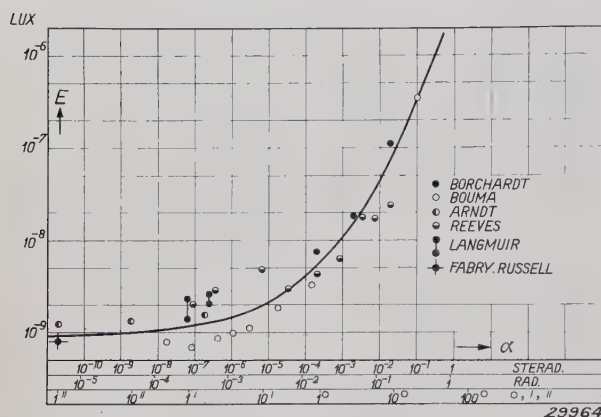


Fig. 1. Intensity of illumination E , which a circular object must give to the eye in order to be seen, as a function of the size of the object (expressed as angle or solid angle within which the object is seen).

illumination E , which a circular source of light must give to the eye in order to be observed is plotted as a function of the angle α within which the source of light is observed ¹⁾. This curve was composed from data of six different authors ²⁾; in spite of the very diverse sources (physical, technical, physiological and astronomic investigations) all the data showed reasonable agreement. It may be seen from fig. 1 that with very small angles of vision (smaller than about 1 min) E is independent of α : for such small points of light it is not the brightness but only the total light intensity which is the important factor. With very large angles (above about 10 degrees) E is proportional to α^2 , i.e. to the apparent area; for such large light spots the dimensions play no further part and it is the brightness alone which determines the visibility. For very small angles of vision the threshold is $E = 10^{-9}$ lux, for very large angles of vision $B = 3.4 \cdot 10^{-10}$ stilb.

In practice we are often concerned with the region which lies between these two extremes and where therefore both the brightness and the dimensions are important for visibility.

In practical navigation a threshold value of $E = 2 \cdot 10^{-7}$ lux is counted on for small angles

of vision, so that for the transition from laboratory experiment to practical observation a factor of 200 is added. This factor seems surprisingly large, but it becomes more comprehensible when we take the following factors into account.

- 1) In the laboratory experiment the eye of the observer was completely adapted to the dark, this was not so in the practical case. The great importance of this factor is shown by the fact that the light of the clear moonless sky raises the threshold value E by a factor of 10 (Russell).
- 2) In the laboratory experiment it is known where the light point is to be expected, this is not true in practice.
- 3) Light points which lie close to the threshold value are often observed for a moment and then lost from view again. For the practical case such an observation is inadequate.
- 4) In the laboratory there is an unlimited time for observation.
- 5) In the laboratory it is possible to concentrate all one's attention calmly on the visual observation.

The factor of 200 mentioned may not, however, be immediately applied to the problem of black-out, since we are in this case concerned with the requirement that the light shall be just not visible, whereas in navigation the requirement is that it shall just be visible. From numerous physiological observations it has been found that the difference in the threshold value may amount to a factor of $1\frac{1}{2}$ to 2 when these two different criteria are applied.

We shall, therefore, find the threshold values for the black-out problem fairly accurately if we multiply the values of E of fig. 1 by a factor 100.

Maximum permissible brightnesses and intensities of illumination

For very large illuminated surfaces we find from the above a maximum permissible brightness of $3.4 \cdot 10^{-8}$ stilb. If we assume that the lighted road surface is diffusely reflecting with a reflection coefficient of 15 per cent (a value which often occurs with granite block pavement, the coefficients are still much lower for asphalt), this means a maximum permissible intensity of illumination of $7 \cdot 10^{-3}$ lux ³⁾. The average level of illumination of highways and streets may therefore not exceed this value. Since the above-mentioned factor of 100, while correct for small angles of vision, will be somewhat

³⁾ It may be noted for the sake of comparison that on a clear moonless night the illumination intensity is about $0.2 \cdot 10^{-3}$ lux, and with a full moon about 0.2 lux.

¹⁾ α is given as an ordinary angle both in radians and in degrees, minutes and seconds.

²⁾ Arndt, *Das Licht* 5, 220, 1935.
Borchardt, *Zs. für Sinnephys.* 48, 176, 1914.
Bouma, (unpublished).
Fabry, *Trans. Ill. Eng. Soc.* 20, 12, 1925.
Langmuir-Westendorp, *Physics* 1, 273, 1931.
Reeves, *Astrophys. J.* 47, 141, 1918.
Russell, *Astrophys. J.* 45, 60, 1917.

too high for very large surfaces, care must be taken that the surfaces which can be illuminated to this level are not larger than absolutely necessary.

For light sources in the form of a point *E* is about 10^{-7} lux for the eye: a light intensity of $\frac{1}{10}$ of a candle may, under favourable weather conditions, be observed at a height of 1 kilometre. This shows that it is of primary importance that the light sources do not radiate any light at all in an upward direction.

In table I are given the data for several intermediate cases. For circular light spots of different diameters *d* (in metres) the maximum permissible intensity of illumination in lux is given which the spot may have and still not be observed from a height of 300, 1 000, 3 000 metres. 30 per cent is taken as the coefficient of reflection of objects, persons, etc. which are situated within the light spot.

Table I

Height	<i>d</i>	0.1 m	1 m	10 m	100 m
300 m		14	0.26	0.013	0.0041
1000 m		135	1.9	0.051	0.0057
3000 m		1200	14	0.26	0.013

The table shows among other things that an intensity of illumination of 1 lux (about the lowest limit at which it is possible to read properly) is permissible with a height of the plane of 1000 m when the light spot has a diameter of 1 m, but for much larger light spots it becomes absolutely inadmissible.

It may also be seen that for very large illuminated areas (100 metres) the visibility decreases only slowly with increasing height of the plane: from 300 to 3 000 metres the permissible intensity of illumination of the area increases only by a factor 3. Small light spots (1 metre) on the other hand disappear very quickly as the plane rises: from 300 to 3 000 metres height the permissible intensity of illumination increases by a factor 54.

It may further be seen from the table that a window of a well-lighted room (100 lux) which has an area of 0.8 sq.m must be provided with a curtain which allows not more than 2 per cent or $\frac{1}{4}$ per cent of the light to pass if it is to be made invisible at 1 000 metres and 300 metres distance respectively. It may be seen from these values that many curtains used in ordinary times are inadequate, even without considering the influence of slits and openings.

General guiding principles for "black-out illumination"

The most important requirements which must be

made of "black-out illumination" are the following:

- a) The general level of the outdoor illumination must be very low (about 0.007 lux).
- b) Even this low level may not be used over larger areas than necessary.
- c) The illumination must be very uniform; this being the only way to obtain a fairly effective lighting without exceeding the permissible level locally.
- d) The sources of light may not radiate any light at all in an upward direction; a few tenths of a candle may already be too much.
- e) Care must be taken that the source of light does not become visible from the air by reflection.
- f) It is desirable that the sources of light radiate a certain amount of light in a practically horizontal direction; in this way the light sources may help the road user by serving as beacons at greater distances. This radiation may not in any case, however, be too strong since the eye would very quickly be blinded at these low levels of brightness.
- g) We shall discuss the influence of the colour of the sources of light at the end of this article.

It has several times been proposed to satisfy requirement a) by lowering the voltage of the electric lamps from a central point. Apart from technical objections connected with this operation, the measure is in itself inadequate. In order to black-out a city satisfactorily in this way the level of illumination would have to be lowered by a factor of about 2 000 when the brightly lighted streets are taken into account; a decrease in voltage from 220 to about 35 volts would be necessary. With such a drastic lowering the visibility in most of the streets would become too poor because of the great lack of uniformity.

In addition there is the fact that at such low voltages the electric lamps would radiate very red light which is very undesirable (see below).

In order to satisfy all the requirements a) to f) it will be necessary to replace the sources of light by others which better answer the purpose.

This could be done by providing the existing light sources in wartime with special fittings, shields, etc. This system has, however, two objections:

- 1) It will be difficult to shield all the existing, often very divergent, types of light sources in the same satisfactory manner.
- 2) When the shield or fitting is damaged without the lamp being broken, the much too intense lamp may suddenly become visible.

The "Protector" lamp

These considerations have led to the development of a special lamp for black-out purposes, the so-called "Protector" lamp, which is manufactured in two different models.



Fig. 2. "Protector" lamp for outdoor illumination.

Fig. 2 is a picture of type I for outdoor illumination. It consists of a 25 watt ⁴⁾ vacuum electric lamp with a specially shaped bulb, almost the entire surface of which has been sprayed with dull black paint. Only a narrow frosted ring has been left free. Since this ring radiates the light chiefly at relatively small angles to the horizon, the light distribution curve of fig. 3 is obtained. In the

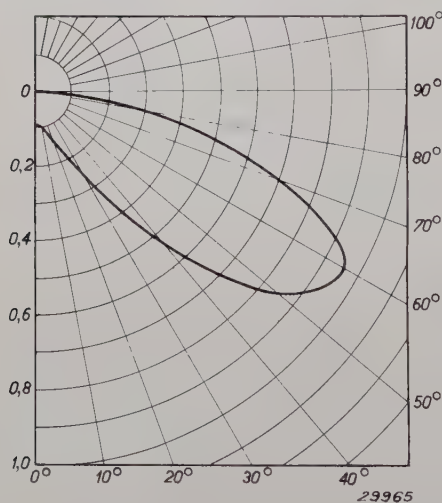


Fig. 3. Light distribution (candle power as a function of direction) of the "Protector" lamp for outdoor illumination.

vertical direction the radiation is at a minimum so that the appearance of a spot with too high a brightness directly under the lamp, as well as the danger of the strong reflection in almost vertical directions is avoided. The great increase of light intensity at larger angles contributes to a more uniform distribution of the light intensity. For angles

smaller than 25° with the horizon the radiation decreases sharply, so that too great a glare is avoided. In the horizontal direction the lamp has a very small intensity (about 0.05 candle), above the horizontal plane no light is radiated. With this light distribution curve the greatest intensity of illumination on the road will occur at the point where the light source is observed at an angle of about 45° with the horizon. If the lamp is mounted at a height of 6 metres the maximum intensity is exactly 0.007 lux; at all other points the intensity is still lower.

If the lamp is mounted at a height of only 4 metres, then outside a circle with a radius of about 6 m from a point directly under the lamp the intensity of illumination will remain below 0.007 lux, while within the circle described an average intensity of about 0.012 lux will be obtained. It may be seen from table I that such a light spot also begins to be invisible from a height of 300 metres.



Fig. 4. "Protector" lamp for indoor lighting.

Fig. 4 gives a reproduction of the "Protector" lamp type II, intended for indoor illumination. In this case also the most important characteristic is that all light in an upward direction is rigorously avoided by shielding, so that even when the effect of the curtains is inadequate, direct light can never be observed by the aviators. This is accomplished by means of a bulb which is also black for the most part with the exception of a frosted window. In contrast to type I the light distribution curve of this type is at a maximum in the vertical direction and there is almost no radiation at angles smaller than 30° with the horizon (see fig. 5). In this way it is made possible to have sufficient intensity of illumination directly under the lamp to carry out certain kinds of work while the light spot is not made unnecessarily large and thereby easily visible.

It is by no means the intention to make the closing of curtains unnecessary by the use of these lamps. They are rather intended to make it possible

⁴⁾ For certain cases a still smaller wattage can be used.

to attain a satisfactory black-out in spite of the often imperfect shielding by ordinary curtains.

As to the use of type I it must be noted that it is impossible at the moment when an air-raid is imminent to change the lamps quickly. The black-out lamps will have to be used during the whole period of possible danger. Over against the disadvantage of having to get along with the very imperfect illumination all that time, is the advantage that when danger actually threatens one is accustomed to this kind of illumination and no extra panic is caused by the sudden dimming of the lights.

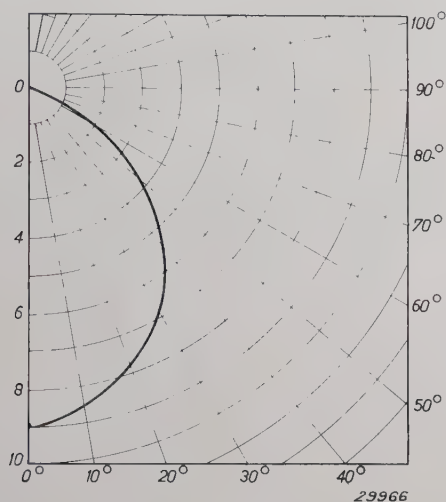


Fig. 5. Light distribution of the "Protector" lamp for indoor illumination.

For those cases where a still lower light intensity is desired, both types of "Protector" lamps can also be supplied with blue coloured ring or window.

It may in conclusion be remarked that the practical experience with "Protector" lamps gained during various black-out tests in the past year was found to be in good agreement with the considerations given here as to visibility.

The colour of the light

Opinions vary very much about the desirability of using coloured lights during air-raids. The use of blue light is very strongly recommended by many, others deny absolutely that blue light offers any advantage over white light. This difference of opinion is understandable when it is kept in mind that there has seldom been an opportunity to carry out a real test of the question, which test would have to consist in the comparison from an aeroplane of a blue and a "white" illumination which gave the same degree of visibility for road users. It has been ascertained that colouring the lamps blue was usually an improvement, but it has not

been possible to ascertain with certainty whether or not this improvement was due exclusively to the decrease in intensity.

The problem of the colour may be formulated most clearly in the following form: for what colour is the relation between the visibility for road users and from a plane most favourable? From this way of putting the question it may immediately be seen that many factors which determine vision under ordinary circumstances must be neglected here since they affect the visibility of the ground and from the air in the same way. We must therefore concentrate attention on the factors which are different from the point of view of visibility from an aeroplane from that of a road user. Among these factors the following are important:

- a) The aeroplane observer is at a greater distance, he sees all objects within a smaller angle of vision and therefore makes more use of the central portion of the eye and less of the peripheral parts, while the road user makes constant use of peripheral vision. Therefore colours for which peripheral vision is relatively sensitive (blue-green and blue) will probably offer certain advantages.
- b) The observer in an aeroplane must try to recognize certain light points out of a collection of very low intensities with here and there vague spots of somewhat greater intensity. This will be easiest when a colour is presented which deviates very much from the colour of starlight. Red or deep yellow coloured light will therefore certainly not be chosen; it may on the other hand offer some advantage to choose a somewhat bluer colour than that of electric light, without, however, using a saturated blue. It must also be noted that when the intensity of red light decreases, the light retains its striking colour until it is almost invisible, while the less saturated colours lying more toward the blue lose their striking colour gradually at lower intensities.

Summarizing we may say that deep red or yellow light sources must certainly not be used, while the use of a somewhat bluer source of light than the electric lamp may offer some advantages. The influence of such variations in colour is, however, infinitesimal compared to the influences discussed above of the intensity, good distribution of light and efficient shielding.

The above is a brief "theory of black-out illumination". It is to be hoped that this theory may never need to be put into practical use.

CARRIER-TELEPHONY ON LOADED CABLES

by F. DE FREMERY and G. J. LEVENBACH. 621.395.44: 621.315.054.3

For the application of carrier-telephony the cable used must have a sufficiently high cut-off frequency. This means that the loading may not be too heavy and therefore considerable attenuation must be accepted in some cases. For long distance connections the loading is, however, already limited by the permissible phase distortion and the transition time, so that the possibility is immediately offered of the introduction of one or more carrier-channels. With very light loading the decrease in attenuation with respect to the non-loaded cable is not very great; but in systems with few channels it is still of practical advantage. For systems with many channels loading offers no appreciable advantage. Finally points are discussed which arise in connection with different carrier-systems.

In order to make the most economical use of a telephone cable between two places far away from each other, so-called carrier-telephony is applied in many cases. This is based upon the following principle. The speech vibrations which must be transmitted for an intelligible telephone conversation occupy a frequency band from 300 to 2 700 c/s. In ordinary telephony, therefore, only these low-frequencies are transmitted. They may however also be used to modulate a carrier-wave which has a frequency of 6 000 c/s for instance. The oscillation obtained contains, in addition to the carrier-frequency, two side bands with frequencies from 5 700 to 3 300 c/s and from 6 300 to 8 700 c/s. Since for the transmission of speech one side band is sufficient, and since in addition the carrier wave itself can also be suppressed after the modulation, the speech has finally been transposed into a vibration with frequencies between 3 300 and 5 700 c/s. The speech thus transposed can be transmitted over the same pair of conductors as the ordinary speech vibrations. The same process can of course also be carried out with carrier waves of higher frequencies. These links running along the same circuit with different frequency bands are called "channels". According to the number of "channels" used at the same time, different systems of carrier-telephony result: in the 1+1 system for example, there is one carrier-wave channel in addition to the ordinary voice-frequency channel; in the 1+4 system, there are 4 carrier channels besides the voice-frequency channel; in the 12 channel system the voice-frequency channel is omitted and there are thus only 12 carrier channels. Systems have even been developed with several hundred channels, in which therefore several hundred conversations may take place at the same time over one circuit. In *table I* the frequency distribution of two common systems is given as an example.

Before the introduction of carrier-telephony an important device already existed for the economical

use of a telephone link: the application of loading-coils. It will appear from the following that the application of carrier-telephony and loading are mutually exclusive to a certain degree, so that a compromise must be made. In order to present clearly the different factors which here play a part, we shall first recall a few general facts about the propagation of electrical oscillations in a conductor ¹⁾.

Table I

Frequency bands in two carrier-wave systems (frequencies in c/s). The 1 + 4 system is used in England.

	1+1 channel system	1+4 channel system
Voice-frequency channel	300 - 2 800	300 - 2 600
1st carrier-channel	3 200 - 5 700	3 400 - 5 700
2nd " "	—	6 600 - 8 900
3rd " "	—	9 900 - 12 200
4th " "	—	13 400 - 15 700

Propagation of oscillations in a cable

If a sinusoidal voltage with an angular frequency ω is applied to the end of a cable, it propagates itself along the cable in the form of a damped travelling wave. The amplitude of the voltage after a distance l is decreased by a factor $e^{-\alpha l}$. The damping α is given by

$$\alpha = \sqrt{\frac{R \omega C}{2}} \sqrt{1 + \frac{\omega^2 L^2}{R^2}} - \frac{\omega L}{R} \quad (1)$$

R is here the resistance, C the capacity, L the self-induction per unit of length of the cable. It is assumed that the leakage of the cable is small compared to ωC and $(\omega C) \cdot (\omega L / R)$, which conditions

¹⁾ Cf. also W. Six, The use of loading coils in telephony Philips techn. Rev. 1, 353, 1936; J. L. Snoek, Magnetic cores for loading coils, Philips techn. Rev. 2, 77, 1937; W. Six and H. Mulders, The use of amplifiers (repeaters) in telephony, Philips techn. Rev. 2, 209, 1937.

are always satisfied by a good cable for the speech frequencies to be transmitted.

A composite oscillation, such as speech, when propagated along a cable, will be continually weakened and at the same time distorted, since according to (1) the damping depends upon the frequency. Due to various factors the distance bridged is limited, since the distortion may not exceed a certain limit if the speech is to be intelligible and the speech vibrations may only be weakened to such an extent that, at the end of the cable or, with longer links, at the next repeater station, they still emerge sufficiently above the ever present disturbances.

For an ordinary cable, in general, $R \gg \omega L$ so that α becomes simply

$$\alpha = \sqrt{\frac{R \omega C}{2}} \dots \dots \dots (2)$$

The attenuation can be reduced by making the resistance and the capacity smaller. The cable is therefore constructed so that its capacity is as small as possible. To reduce the resistance a large cross section of copper is necessary. A limit prescribed by economic considerations is soon reached.

There is however another possibility of decreasing the attenuation, namely by increasing the self-induction. Formula (1), for the case where $\omega L \gg R$, then becomes:

$$\alpha = \sqrt{\frac{R \omega C}{2}} \cdot \sqrt{\frac{R}{2 \omega L}} = \frac{R}{2} \sqrt{\frac{C}{L}} \dots \dots (3)$$

The attenuation is here smaller by a factor $\sqrt{R/2\omega L}$ than in the case of formula (2) and it is also independent of the frequency, so that the speech is no longer subjected to linear distortion if we neglect the lowest frequencies at which the condition $\omega L \gg R$ may not be satisfied.

The practical method of increasing L in most cases is by loading: at regular distances self-induction coils are introduced into the circuit.

Since with increasing L the attenuation becomes steadily smaller, see equation (3), it seems advisable to apply heavy loading, *i.e.* to introduce large coils at short distances. Aside from the fact that here also economic considerations would set a limit, an objectionable influence is exerted by heavy loading in the transmission of higher frequencies. We shall deal with this influence in some detail.

Loading and cut-off frequency

From equation (3) we concluded that α becomes independent of the frequency when $\omega L \gg R$. This

is, however, only true when the self-induction L , like the resistance R and the capacity C , is distributed uniformly along the cable. For a loaded cable, where the self-induction is concentrated chiefly at definite points, (3) is valid only in a definite frequency range, namely, as long as the wave length is large with respect to the length of section s , *i.e.* the distance between two successive coils. Above this frequency range the attenuation α begins at a definite frequency, the cut-off frequency ω_0 , to increase sharply so that higher frequencies than this are practically not transmitted. The loaded cable thus behaves as a low-pass filter, and the cut-off frequency is given approximately by

$$\omega_0 = \frac{2}{\sqrt{L_s \cdot s C}}, \dots \dots \dots (4)$$

where L_s is the self-induction per section (*Cf.* Philips techn. Rev. 2, 210, 1937 for this formula). Since the self-induction of the conductor is in general much smaller (0.6 mH/km) than that of the coils, L_s is approximately equal to the self-induction of the type of loading coil used. The larger L_s *i.e.* the heavier the loading, the lower the cut-off frequency becomes, and the narrower the frequency range in which formula (3) is valid. In *fig. 1* the attenuation for various common types of loading is plotted as a function of the frequency.

It would of course also be possible to obtain a high cut-off frequency when large self-inductions L_s are used, by decreasing the length of the sections s , see equation (4). The attenuation is at the same

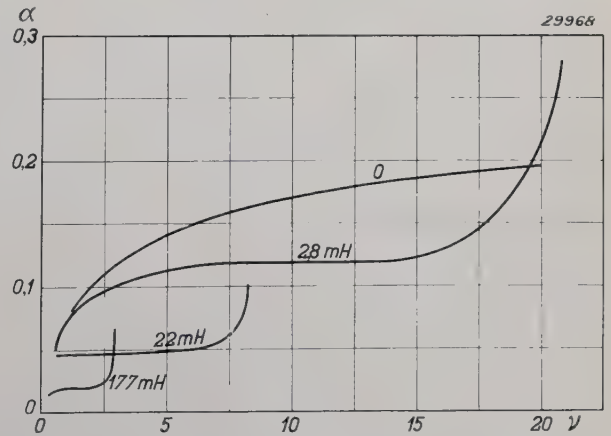


Fig. 1. Attenuation curves of a cable with different types of loading. The attenuation α in Nepers²⁾ is plotted against the frequency ν in kc/s. Curve 0 is for a non-loaded cable, while in the other three cases drawn loading is applied with coils of 2.8 mH, 22 mH and 177 mH respectively. The length of section is 1830 m, the core diameter 0.9 mm and the cable capacity is 0.0385 μ F/km.

²⁾ An attenuation of 1 N (Neper) means a decrease in voltage by a factor $1/e = 1/2.718$; a difference in level of 0.12 N thus corresponds to a voltage ratio $1/e^{0.12} = 0.89$.

time still more reduced, since the self-induction per unit length, $L = L_s/s$, is greater. If the latter is kept constant by decreasing L_s proportionally to s , then with constant attenuation an increase of the cut-off frequency is achieved (ω_0 then increases inversely proportional to s). This is obvious even without formulae, because proportional reduction of L_s and s means a more uniform distribution of the total self-induction of the cable, and therefore a better approximation of the limiting case of a homogeneous cable in which the "cut-off frequency" is infinite. This method cannot, however, generally be applied in practice since the shortening of the sections involves considerably more expense because, in addition to more coils, extra coil cases and man-holes are necessary. In most countries a section length of 1.83 km is used (in Germany 1.7 km), which length is assumed in the curves of fig. 1. It is immediately clear from fig. 1 that heavily loaded cables with coils of 177 mH cannot be considered for carrier-telephony. When there is only one carrier channel above the low-frequency channel (1+1 channel system) frequencies up to 5 700 c/s must be transmitted. A sufficiently high cut-off frequency is necessary for this. A lighter loading is thus necessary, and this is even more the case for carrier-systems with a larger number of channels. With light loading, for instance with coils of 22 or 2.8 mH, however, as is shown by fig. 1, the attenuation in the flat part of the curve which can be used effectively is much greater than with heavy loading. This means that for a given distance a greater number of repeater stations or a larger copper diameter would be necessary. By the application of carrier-telephony the cable is used more efficiently, but at the same time the connection is more expensive (especially if we also consider the cost of the carrier-apparatus in the terminal stations), so that it is natural to ask whether there is any other advantage.

Transition time and phase distortion

In the case of links over long distances there is, however, another reason for changing over to light loading, namely distortion. The abovementioned linear distortion which occurs because the attenuation at the ends of the range transmitted is no longer independent of the frequency, can be corrected to some extent by balancing networks which together with the intermediate repeaters have a suitable characteristic. There are, however, other causes of distortion.

Oscillations with different frequencies are in

general propagated along the cable with different speeds. With long distances considerable differences in transition times can occur between the lowest and the highest frequencies of speech, which gives the latter an unpleasant character and finally makes it unintelligible. This is called phase distortion. For the difference in transition time Δt between two frequencies ω_1 and ω_2 which are not too close to the frequency ω_0 , the following formula is approximately valid:

$$\Delta t = \frac{l(\omega_1^2 - \omega_2^2)}{s\omega_0^3} \cdot \cdot \cdot \cdot \cdot \quad (5)$$

Formula (5) may be derived as follows. Every coil causes a certain rotation of phase φ_s of the voltage; the sections of cable between the coils also cause a phase rotation, which is however small, so that we may neglect its contribution. The equivalent circuit of one section of the cable is drawn in fig. 2, in which the ohmic resistance of the cable is neglected. The section is considered as a cell of a low-pass filter which is shut off from the cable at one side by the impedance $Z = \sqrt{L_s/C_s}/\sqrt{1 - (\omega/\omega_0)^2}$. C_s is the capacity per section. For a voltage E_1 on the left hand terminals of the coil the impedance is

$$j\omega L_s + \frac{1}{\frac{Z}{j\omega C_s/2} + \frac{1}{Z}};$$

for the voltage on the right-hand terminals the impedance is

$$\frac{Z}{\frac{1}{j\omega C_s/2} + \frac{1}{Z}}.$$

The ratio of the voltages becomes:

$$\begin{aligned} \frac{E_1}{E_2} &= \frac{Z}{(1 + Zj\omega C_s/2) \left(j\omega L_s + \frac{Z}{1 + Zj\omega C_s/2} \right)} = \\ &= \frac{Z}{Z(1 - 2\omega^2/\omega_0^2) + j\omega L_s}. \end{aligned}$$

When worked out further this gives for the phase angle φ_s between E_1 and E_2 the relation

$$\sin \varphi_s = 2 \frac{\omega}{\omega_0} \sqrt{1 - \left(\frac{\omega}{\omega_0}\right)^2} \cdot \cdot \cdot \cdot \cdot \quad (6)$$

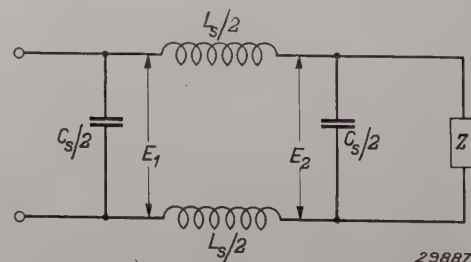


Fig. 2. Equivalent circuit for the loaded cable. A section length is considered as a cell of a low pass filter. C_s is the capacity of the cable per section, L_s is the self-induction concentrated in the loading coil, Z is the cable impedance. A phase rotation φ_s occurs between the voltages E_1 and E_2 .

A transition time for the wave of φ_s/ω corresponds to the phase rotation φ_s . For the distortion, however, it is not a question of the transition time of the waves, but of the "group transition time" of a finite wave train. The group transition time per section of the cable is

$$t_s = \frac{d\varphi_s}{d\omega}.$$

With equation (6) one obtains

$$t_s = \frac{2}{\omega_0} \frac{1}{\sqrt{1 - \left(\frac{\omega}{\omega_0}\right)^2}},$$

and for the transition time over a length of cable l :

$$t = \frac{l}{s} \frac{2}{\omega_0} \frac{2}{\sqrt{1 - \left(\frac{\omega}{\omega_0}\right)^2}} \approx \frac{l}{s} \left(\frac{2}{\omega_0} + \frac{\omega^2}{\omega_0^3} \right) \dots (7)$$

For the difference in transition times between two frequencies equation (5) follows from the above.

On the basis of intelligibility tests the C.C.I.F. (Comité consultatif international des communications téléphoniques à grande distance) has prescribed that the "phase distortion" (the difference in group transition time) on international lines may not be more than 15 milliseconds when the frequencies 300 and 2 400 c/s are taken for $\nu_1 = \omega_1 \, 2\pi$ and $\nu_2 = \omega_2 \, 2\pi$. For the maximum distance to be linked l_m in kilometres, when the cut-off frequency $\nu_0 = \omega_0 \, 2\pi$ is calculated in kc/s the following value is found:

$$l_m = 30.4 \cdot \nu_0^3 \dots \dots \dots (8)$$

In table II the maximum distance calculated with this value is given for different types of loading, while equation (3) is represented graphically in fig. 3. While it is possible to raise the limit given by the differences in transition time by means of correcting networks, it nevertheless remains necessary to apply light loading for long distances. In loading with coils of 22 mH phase distortion is no longer felt, even at the greatest distances

Table II
Limitation of the distance bridged by phase distortion and transition time. Section length 1.83 km.

Loading with coil of (mH)	Cut-off frequency	l_m (km)	l'_m (km)
177	~ 2.85	700	2 500
22	~ 8.0	15 500	6 900
2.8	~21	> 100 000	17 000

³⁾ The precise specification states that the phase distortion may be 10 milliseconds for the frequencies 300 and 800 c/s and another 5 m sec for 800 cycles and the highest frequency used. For the latter a smaller value is taken here as actually applied, because, if equation (4) is also to be used for the 177 mH loading, the frequency must be sufficiently far below the cut-off frequency.

occurring. The higher cut-off frequency, which then automatically prevails, makes it possible to apply a 1+1 carrier-system. This is actually the way in which carrier-telephony developed: the great international lines were given a higher cut-off frequency, and this opened the way for the introduction of carrier-systems.

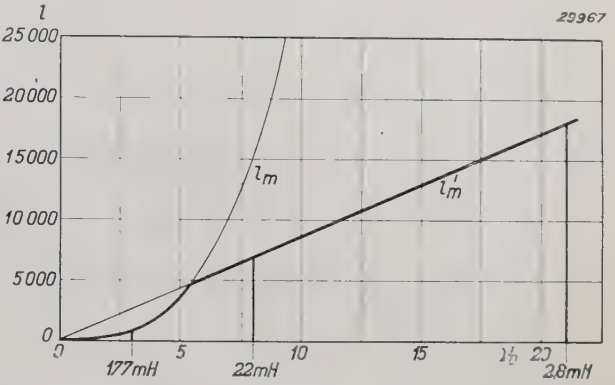


Fig. 3. Limitation of the distance to be bridged due to phase distortion and transition time. The maximum distance in km: $l_m = 30.4 \, \nu_0^3$ or $l'_m = 860 \cdot \nu_0$ is plotted as a function of the cut-off frequency ν_0 in kc/s. Below about 5 000 km the phase distortion, and above that distance the transition time is the dominating factor. The three cases of loading with coils 177 mH, 22 mH and 2.8 mH respectively are specially indicated.

With extremely long distances ($> 5 \, 000$ km) there is an even stricter limitation of the permissible loading. The delay in arrival of the speech at the ear of the one spoken to, due to the finite speed of propagation of the speech frequencies along the cable, may lead to disturbances in the conversation even with transmission which is quite free of distortion. When the one speaking pauses, for instance, and his partner asks a question during the pause, the question only arrives after the first speaker has again begun to talk. It has been shown statistically that even with a transition time of 0.4 sec disturbances occur during the conversation in half of all the calls made. Therefore a time of 150 milliseconds has been fixed by the C.C.I.F. as a maximum permissible transition time t'_m for international communication. Here again it is not a question of phase distortion, but of group transition time. For loaded lines the following holds approximately for the transition time (see equation (7)):

$$t = \frac{l}{s} \cdot \frac{2}{\omega_0} \dots \dots \dots (9)$$

The distance which can be bridged when the maximum permissible transition time is taken into consideration is:

$$l'_m = \frac{s}{2} t'_m \cdot \omega_0.$$

With the above-mentioned value of t'_m and a cut-off frequency ν_0 in kc/s we obtain for l'_m in kilometres:

$$l'_m = 860 \cdot \nu_0 \cdot \dots \cdot \quad (10)$$

This function is shown in fig. 3. The values of l'_m for several loadings are indicated in table II. It may be seen that with distances greater than 5 000 km loading which is not yet accompanied by inadmissible phase distortion already causes too long a transition time.

Furthermore it must also be taken into account that in case of insufficient matching or inaccurate tuning of the balancing network in the end stations⁴⁾ the speech frequencies may be reflected at the end of the cable, and then after a certain interval return to the speaker as an echo. With a given intensity this phenomenon is the more disturbing the longer the interval, and forms another restriction on the transition time⁵⁾, unless it is neutralized by means of so-called echo suppressors.

For these reasons the loading for linking the longest distances must be lighter than is prescribed by the phase distortion. In loading with 2.8 mH coils which are suitable for the purpose, the cut-off frequency is so high that 3 or 4 channels may be introduced above the low-frequency channel.

Influence of loading on the distance between repeaters

If we compare in fig. 1 the above-mentioned 2.8 mH loading with the heavy loading 177 mH coils, it is seen that the advantage to be derived from loading, namely decrease of the attenuation, has disappeared for the most part. The difference from the non-loaded cable does not appear very great, and it is natural to ask whether light loading for long distances really serves a useful purpose. Since a change to entirely non-loaded cables offers much more scope to carrier-telephony we shall give briefly the considerations which argue for the application of light loading.

The distance necessary between repeaters on a line depends upon the attenuation which may be permitted between two repeaters, and this latter in turn on the permissible transmitting and receiving level. The minimum receiving level required is determined by disturbances. A fundamental restriction is formed by the noise caused by the thermal motion of the electricity and the shot effect

in the amplifier valves. Of much greater importance, however, are the disturbances due to induction of external fields (near by high power lines, for instance) and to so-called cross-talk. The latter consists in the fact that the modulation of one conversation, whether or not intelligible as such, also becomes audible in other circuits or channels in the same cable.

Various causes of cross-talk may be pointed out:

- 1) the lack of linearity of the loading coils;
- 2) the mutual capacity between the different pairs of conductors;
- 3) the mutual induction effect.

It is clear that the non-linearity of loading coils leads not only to distortion of the speech, but in the case of carrier-telephony to cross-talk also between the different channels.

The harmonics of the speech frequencies occurring in the low-frequency channel fall in the carrier-channels, while the combination tones of different frequencies in one carrier-channel may appear as disturbances in the low-frequency channel. The disturbance increases when the amplitude of the speech currents on the loading coils in the line are increased. In order to keep this kind of cross-talk within permissible limits, therefore, the transmitting level must not be taken too high⁶⁾.

The mutual capacitive and inductive effects of the pairs of conductors is limited as much as possible by special construction of the cable.

There are two main types of construction. In the first type the quads consist of two twisted pairs of wires which are twisted together (D.M. cable), in the second type of four conductors which are twisted together in such a way that in a cross section the wires lie at the four points of a star (star cable). The mutual effects between two pairs and between the pairs and the phantom circuit (see below) are hereby very much decreased. In order also to limit the mutual influence between the quads, different degrees of twisting are chosen for the adjacent quads in one layer, and opposite directions of lay for successive layers in the cable.

In the case of four-wire lines the most important part of the remaining effect is the mutual effect of two pairs of opposite direction of transmission. This effect will be greater, the greater the difference of the speechlevels of the two pairs in question. The maximum difference in level occurring is equal to the amplification applied in each repeater station; in the neighbourhood of a station the outgoing speech is amplified to the normal transmitting level, while the incoming speech has been subjected to attenuation by the length of cable through which

⁴⁾ See in this connection the article by Six and Mulders cited in footnote 1).

⁵⁾ The limits of the transition time set by the echo are given in the C.C.I. White Book, part I bis, page 148.

⁶⁾ We hope to return to these questions shortly in this periodical, and to discuss particularly measurements which have been carried out here with an artificial cable.

Table III
Attenuation and distance between repeaters in different cables for carrier telephony

Carrier-System	Type of Cable	Permissible amplification in N	Non-loaded, 40 lbs cable		Loading	Loaded 40 lbs. cable		
			Attenuation per km at highest frequency in N	Possible distance between repeaters in km		Cut-off frequency in c/s	Attenuation per km at highest frequency in N	Possible distance between repeaters in km
1+1	One cable with separated quads	~4.5	0.09	50	H 22	8 000	0.026	170
1+4	One cable with separated quads	~4.0	0.11	36.5	H 2.8	21 000	0.065	60
					B 4.6	23 500	0.045	90
1+4	two cables	~5.0	0.11	45.5	H 2.8	21 000	0.065	80

*) The letter H indicates that the section length $s = 1.83$ km, the letter B that $s = 0.915$ km.

it has passed. The permissible amplification is limited by this and by the other disturbances mentioned. The general disturbances by induction from the outside decrease sharply at high frequencies due to the increasing effectiveness of the screening by the cablesheath. In order to profit from this property which is very favourable for carrier-systems with many channels, every effort is made to decrease the cross-talk which increases at higher frequencies, by laying the cores of opposite directions of transmission in quite separate cables. But also in the case of one cable for both directions cross-talk, even at high frequencies, can be kept so low that a satisfactory amplification becomes possible. To do this the two branches of a four-wire circuit are not led to pairs of the same quad but to pairs which lie in different parts of the cable. The pairs which lie between then function as screening to some extent. Separate groups are thus formed for the two directions of transmission 7).

The maximum permissible amplification is given in table III for several cases. At the same time the table gives the attenuation per km of a non-loaded cable with 40 lbs conductors for the highest frequency to be used i.e. 5 700 c/s with the 1+1 system and 15 700 c/s with the 1+4 system of table I. From this follows the necessary distance between the repeaters which is given in the next column.

The normal distance between repeater stations for voice-frequency telephony is about 80 km with four-wire repeaters and 20 lbs conductors. It may be seen from the table that even with 40 lbs conductors the repeater stations of a non-loaded telephone line cannot be placed at this distance. Even with 55 lbs conductors which make the cable

quite expensive, this distance is not reached. If it is desired to use a normal distance between the repeaters of about 80 km — and this is desirable for economic and practical reasons — the attenuation of the cable must be reduced by suitable loading. The values for this are also given in table III. It may be seen that a distance between repeaters of 80 km is made possible by the loading. Only in the case of the 1+4 channel system in one cable the attenuation is still too high when the coils are placed at intervals of 1.83 km. In this case therefore heavier conductors would have to be used or a shorter section length, for instance 0.915 km.

Summarizing, we may say that loading with light coils such as those of 2.8 mH may be desirable and economical for long distances.

Different carrier-systems

While it has been found that for long distances only a light loading is desirable, and that with this loading carrier-telephony can be applied without making any sacrifices, the decision is not so simple for short distances. A comparison of several systems will show the truth of this statement. The cable loaded with 2.8 mH coils gives an attenuation of 0.12 N/km with 20 lbs conductors in the “flat” region (see fig. 1), that with 177 mH coils gives an attenuation of 0.02 N/km. This means that with the light loading in question the distance between the repeaters along the line would have to be six times as small, or the copper weight six times as great as with heavyloading.

However, what is lost, in a manner of speaking, in the height of the attenuation curve, is regained in the width of the flat region, by the possibility of more channels. With 2.8 mH loading, 1+4 channels can be used for every pair of quads. With every quad, however, there is an extra connection available, namely the phantom circuit where the two con-

7) If necessary, cross-talk can be further reduced by means of special compensating networks.

ductors of one direction of transmission are used together once more as a conductor, see *fig. 4*. Because the increasing cross-talk with higher frequencies between the phantom and the main

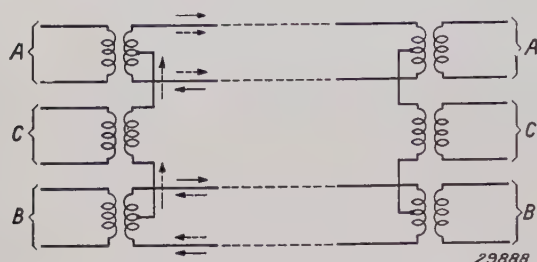


Fig. 4. One twin-core conductor provides three circuits: two main circuits A and B and the phantom circuit C.

circuit it is practically impossible to introduce more than one carrier-channel on these phantom circuits, so that only the 1+1 system can take advantage of this extra circuit. Two pairs may therefore provide three fourwire connections (two main circuits and one phantom circuit) with 177 mH coil loading⁸⁾; with 22 mH there can be six, since in each connection there can be one more carrier-channel, and with 2.8 mH there can be ten (by application of the 1+4 system in which the use of phantom circuits is no longer possible).

Over against this advantage of carrier-telephony is the necessity of more equipment in the terminal stations, which, especially in the case of short cables, may constitute an important part of the total expense. No general conclusion is possible which would point out a definite system as the most economical one, but for each case it is necessary to balance the different factors against each other. The decision will often be influenced by the presence of other lines on the traject in question and by the prospect of later expansion.

With multi channel carrier-systems still other

factors play a part. In England for example a 12 channel system is used for which frequencies up to about 60 kilocycles are necessary. The very high cut-off frequency required immediately excludes the above-mentioned normal loading, especially because with the ordinary section-length the necessary self-induction per section would already be smaller than the self-induction of the cable itself. Only with section-lengths reduced to $\frac{1}{3}$ or less, loading would provide any advantage in copper-weight or repeater-distance. It is, however, simpler in this case to use non-loaded cables. At the same time the latter have the advantage that when expansion of the number of calls becomes necessary, there is no sharp cut-off frequency which prevents increasing the number of channels.

Another example is the 9/17 channel system, developed by Philips. Frequencies up to 72 kilocycles are used. If 9 channels are included in this frequency range with a carrier-spacing of 8 kilocycles, the advantage is obtained that considerably simpler filters can be used for separating the channels. In the same frequency band, however, 17 channels can be included with carrier spacings of 4 kilocycles.

When non-loaded cables are used more care must be devoted to removing the linear distortion by means of balancing networks, as may be seen in *fig. 1*. At high frequencies the attenuation curve becomes flatter and flatter, which is understandable since at higher frequencies the condition $\omega L \gg R$ for formula (3) is automatically more and more satisfied. Balancing is therefore easier here. It is most difficult in the voice frequency region, especially in the case of long cables, because then an automatic compensation becomes necessary in the balancing networks for the dependence of the cable constants on the temperature. In this connection the omission of the frequency channel or its use only for short distances may mean a considerable simplification and saving. This is always done in multi channel carrier-systems and may even be considered in a system with only 4 carrier-channels.

⁸⁾ The phantom circuit is of course again loaded, and in such a way that it is given the same attenuation as the main circuit. Since the ohmic resistance of the phantom circuit is about one half and the capacity less than twice the value in the main circuit, a smaller self-induction of the coils is sufficient, for instance 63 mH, with 177 mH in the main circuit. In this way one arrives at coils of 177/63 mH, and in the same way at 22/9 mH in the following case.

⁹⁾ Although the resistance R also increases due to the skin effect, nevertheless $\omega L/R$ becomes steadily greater.

THE ROLE OF MERCURY LAMPS WITH FLUORESCENT BULBS IN PHOTOGRAPHY

by J. A. M. VAN LIEMPT.

621.327.3: 666.265 : 771.44

In a previous article¹⁾ we pointed out that ordinary mercury lamps, either high or super high pressure (HO or HP lamps) are unsuited for photographic purposes when a correct reproduction of colours is desired. The difficulty with these lamps is that they give too much blue and too little red radiation. This difficulty can be met, however, by providing the mercury lamp with a fluorescent bulb (HPL lamp), whereby the ultraviolet radiation of the discharge is transformed by means of a fluorescent substance on the inside of the bulb into visible radiation which consists in part of red radiation. The excess of blue and the lack of red of the ordinary HP lamp is hereby corrected. It may therefore also be expected that the photographic colour reproduction will be considerably better, especially when only panchromatic plates are used.

A. Normal panchromatic material

Light source	Colour reproduction		
	red	yellow	blue
HP 300	50	70	160
Na light	120	120	40
Na- + Hg light	90	90	90
HPL 300	70	70	100
Daylight	70	40	160

B. Special red-sensitive panchromatic material

Light source	Colour reproduction		
	red	yellow	blue
HP 300	50	70	160
Na light	120	110	40
Na + Hg light	90	90	90
HPL 300	90	90	90
Daylight	120	70	120

¹⁾ Philips techn. Rev. 2, 24, 1937.

The tables below show the results of some measurements carried out with the Agfa colour chart with normal as well as special red-sensitive panchromatic material illuminated with the lamp HPL 300. For the sake of comparison we also give the colour reproduction with daylight, with light from the ordinary HP lamp and from the sodium lamp, and with sodium and mercury light combined in the correct proportion as previously discussed¹⁾.

From these results it may be seen that a very good colour reproduction may be obtained with HPL lamp and extra red-sensitive panchromatic material. This fact is also demonstrated in fig. 1.

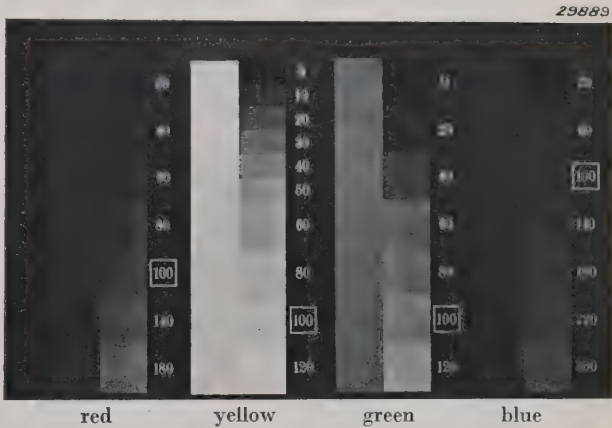


Fig. 1. Photograph of an Agfa colour chart on special red-sensitive panchromatic material, illumination by a mercury lamp provided with a fluorescent bulb.

The advantage of this lamp over the much used combination of mercury and sodium lies in the fact that only one lamp need be employed. However, one is confined to the use of a definite kind of plate, while with mercury-sodium light good results are obtained with ortho as well as panchromatic plates. It remains to be seen which light source is to be preferred; in any case, in view of the results given above, the new HPL lamp deserves the attention of every photographer.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

- 1330:** J. Sack: Le transport du métal dans l'arc de soudure (Rev. univ. Mines **14**, 439 - 443, June 1938).

In this lecture given at a congress in Liege (Febr. 1938), the way was discussed in which the transport of molten material from the welding rod takes place. For part of the material of this lecture we may refer to articles contributed by the author to this periodical (Philips techn. Rev. **1**, 26, 1936, **2**, 129, 1937), while the author intends to deal with the latest research on this subject in a coming article also in this periodical.

- 1331:** J. Sack: Est-il logique de fixer une limite supérieure pour la résistance à la traction du métal d'apport dans les cahiers des charges (Rev. univ. Mines **14**, 484 - 487, June 1938).

For the material of this lecture given at Liege (Febr. 1938) the reader is referred to: Philips techn. Rev. **3**, 283, 1938.

- 1332:** K. F. Niessen: Erdabsorption bei horizontalen Dipolantennen (Ann. Physik **32**, 444 - 458, June 1938).

In the case of a horizontal infinitesimally small dipole aerial, above an earth considered flat, part of the energy emitted is absorbed by the earth. This part is calculated as a function of the height above the earth, the wave length, the dielectric constant of the earth and its conductivity.

The progress made with respect to earlier calculations on this problem consists in the fact that account may now also be taken of the finite conductivity of the earth's surface, while previously the earth had to be treated as a pure dielectric. The integrals which occur in the calculation can easily be worked out graphically for a definite kind of soil, wave length and height. The formulae obtained here are of importance in deciding whether a horizontal or a vertical aerial should be chosen with a given kind of soil and a given wave length for the sake of minimum absorption by the earth.

- 1333:** J. H. de Boer: Atomic irregularities in simple compounds (Chem. Wbl. **35**, 542 - 552, July 1938).

In this lecture, which was held in Amsterdam on April 21st 1938 to commemorate the 35th anniversary of the Netherlands Chemical Society, it was shown how our ideas on the subject of the transport of material and electricity through crystals of simple chemical compounds have developed in the last 35 years.

- 1334:** F. M. Penning: The elementary processes taking place in the breakdown of gases between plane parallel plates (Ned. T. Natuurk. **5**, 33-56, Mar. 1938).

In this article a survey is given of the phenomena which occur upon the setting in of an electrical discharge between large parallel plates. The manner in which the ionization coefficient depends upon the potential difference traversed per free path is dealt with. From this dependence an estimation is made for the case of oxygen of the number of negative ions formed by an electron per volt and per centimetre. The result obtained agrees satisfactorily with the results of direct measurements. For various gases and mixtures of gases it is possible to calculate what parts of the energy obtained by the electrons from the electric field are used for ionization, for excitation of electron levels or vibration levels, for elastic collisions and for the acceleration of electrons.

The different processes which produce new electrons are also discussed. For low values of the potential difference traversed per free path, it follows from the variation of the quotient of the number of ions freed by the cathode and the number of ionizations in the gas, that for air the positive ions probably pass over in larger groups (clusters), which are only able to free electrons to a smaller extent; for the rare gases the photoelectric effect becomes important in this region.

Several qualitative calculations are given on the question of whether the breakdown with long spark gaps and with overvoltage in air at 1 atmosphere must be ascribed to a collapse of the space charge or to thermal effects. Finally several remarks are made about the passage of sparks at very high and very low voltages.

GENERAL SURVEY OF THE PHILIPS PRODUCTS

INCANDESCENT LAMPS for

general lighting purposes

roads, streets, grounds, platforms, houses, offices, factories, ships, schools, churches, shops, show-windows, exhibitions, museums, barracks, air-raid protection

projectors

frontages, show-windows, stage, photographic studios, film studios, aerodromes, light-houses and other beacons, aeroplanes, locomotives, military searchlights, motor-cars, motor cycles, bicycles

projection purposes

standard and sub-standard film, picture scanning in sound-film installations, projection of stationary images (*slides*), micro-projection (*tungsten arc and tungsten ribbon lamps*)

publicity and festive lighting

decorative lighting (*long and short tubular lamps*) in theatres, restaurants, ships

miscellaneous special purposes

telephone exchanges, mines, rail- and tram-ways, army

various apparatus and instruments

workbenches, sewing machines, vacuum cleaners, measuring apparatus, switchboards, wireless receivers, medical instruments

GAS-DISCHARGE LAMPS AND THEIR GEAR

sodium lamps for

outdoor lighting (*roads, grounds, frontages, publicity hoardings, aerodromes*)
indoor lighting (*industrial, photographic studios*)
scientific purposes

mercury lamps, with ordinary or fluorescent bulb, either separately or together with incandescent lamps, for outdoor lighting (*streets, grounds, platforms, advertising hoardings*)
indoor lighting (*industrial, offices, shops, show-windows, photographic studios*)
photography (*printing, copying films*)
projection (*standard and sub-standard film, microphotography, meteorological purposes*)
irradiation (*biological and chemical processes*)
projectors (*aviation grounds, aeroplanes, searchlights*)
ultraviolet irradiation (*producers of fluorescence*)

fluorescent mercury lamps (*tubular shape*)

for decorative and architectonic indoor lighting

neon tubes for

publicity purposes
plant irradiation
the lighting of aviation grounds

discharge tubes for

demonstration purposes (*instruction*)

transformers, choke coils and condensers

for gas discharge lamps

FITTINGS FOR INCANDESCENT AND GAS-DISCHARGE LAMPS, also bicycle reflectors and dynamos

TUBES AND VALVES

oscillator tubes

triodes and pentodes with high and low outputs, for connection to D.C. mains, A.C. mains and batteries for transmitters and receivers (radio and television), high-frequency furnaces, measuring apparatus, apparatus for diathermy and ultra-short wave therapy

amplifier tubes

triodes, tetrodes, pentodes, hexodes. Special amplifier tubes for sound-amplifiers and measuring amplifiers (*for instance electrometer triodes*)

valves with combined functions

triode-hexodes, heptodes, triode-heptodes, octodes, other combined systems

rectifier valves with high vacuum and with gas-filling for receivers, amplifiers, transmitters, H.T. installations, industrial and other rectifier installations

relay valves for

television purposes, measuring apparatus, rectifier installations with adjustable voltage output

regulating tubes

voltage stabiliser tubes in the form of gas discharge tubes
current regulator tubes in the form of iron wire resistances and with gasfilling for *wireless receiving and transmitting apparatus, amplifiers, measuring instruments, and for the charging of batteries*

photo-electric cells with glass bulbs and quartz bulbs with gasfilling, with high-vacuum and amplification by secondary emission (*for instance electron multipliers*) for soundfilm installations, television installations, supervisory installations, industrial and scientific purposes

cathode ray tubes with

electrostatic, magnetic, and half-electrostatic

half-magnetic deflection, with screen diameters of from 3 to 39 cm, *for photographic recording and visual observation of oscillograms and for television purposes*

X-ray tubes, (see X-ray installations)

rare gas cartridges for protection against over-voltages in heavy current mains, low voltage mains, aerials and parts of a circuit

tubes for special purposes

iconoscopes *for television transmitters*
magnetrons } *for generating decimetre waves*
acorn valves }
thermo-couples
counting tubes *for alpha, beta, gamma and cosmic rays*

TRANSMITTING APPARATUS

broadcasting installations

stationary transmitters

installations for aviation

aircraft transmitting-receiving equipments
direction-finding equipments
radio compasses
ultra-shortwave and medium wave radio beacons
aerodrome transmitters and receivers

marine installations

coastal transmitters
ship's transmitters and receivers
direction-finding installations
radio beacons

studio and reporting car installations

transportable and portable transmitting-receiving equipments

receivers for special purposes

ultra-short wave radio links

WIRELESS RECEIVERS AND THEIR PARTS

wireless receivers for

connection to A.C. mains
feeding by batteries
feeding by D.C. as well as A.C.

radio gramophones

electric gramophones (*for connection to wireless sets*)

loudspeakers in cabinet, for use as extension speakers

car radio

aerial protection devices

aerial systems for interference-free reception,
for connection to one wireless set
collective connection to a large number of sets

pick-ups

condensers (*dry and wet electrolytic condensers, also mica, paper and ceramic condensers*)
fixed condensers
variable condensers
trimmer condensers

loudspeakers

resistances (*wire resistances and high-ohmic resistances*)
potentiometers

choke coils, loudspeaker transformers

waveband switches

converter units

TELEVISION TRANSMITTING INSTALLATIONS

fixed and transportable types

X-RAY INSTALLATIONS AND ACCESSORIES

for medical purposes (*diagnostics, therapy*) and material research (*macroscopic and microscopic examination*)

X-ray apparatus for all purposes

X-ray tubes (*with protection against undesired radiation and high tension*) for
diagnostics (*stationary and rotating anode*)
therapy
contact therapy (*50 kV*)
superficial therapy (*100 kV*)
deep therapy (*up to 1000 kV*)
material research

valve tubes, with high-vacuum and with gas-filling, for diagnostics, therapy and material research

condensers

tube stands, couches and other auxiliary apparatus
accessories for X-ray work

HIGH TENSION INSTALLATIONS for

nuclear research (2 MV and higher)

production of neutrons (at 600 kV equivalent to 300 g Ra + Be)

testing of insulation

with high direct voltages
with impulse voltages (4 MV stationary and up to 1.2 MV transportable ready for operation)

HIGH FREQUENCY FURNACES

MEASURING APPLIANCES AND THEIR AUXILIARY APPARATUS

cathode ray oscillographs for
making all oscillations visible

vibration pick-ups for

studying mechanical and acoustical vibration phenomena

cathode ray pressure indicators (Philips and Shell) for

the study and inertialess recording of pressure phenomena (*indication of internal combustion engines, examination of pumping installations, pressure surges in pipes for liquids*)

wave meters

recording field strength meters for examining

the field strength of transmitters

the radiation of receivers

fading phenomena

measuring bridges for measuring all impedances (*faults in cables, earth resistances, armature windings*)

measuring cells and L.F. oscillators for

the measurement of the specific resistance of liquids with the measuring bridge

the establishment of the ash content of sugar juices with the measuring bridge

generators for

all L.F. and H.F. measurements in wireless receivers and amplifiers in laboratories, factories and workshops

frequency modulators for

making visible the selectivity curves of wireless receivers

output meters for

receivers and amplifiers

universal apparatus for complete examination of

wireless receivers

radio valves

phonometers for

demonstrating difference in quality of power valves and rectifier valves in wireless receivers

ammeters

moving coil instruments *for measuring*

direct current

alternating current (frequency up to 1000 c/s), with metal rectifier cell

alternating current (radio frequency), with thermo-cross

voltmeters

moving coil instruments *for measuring*

D.C. voltages

A.C. voltages (frequency up to 1000 c/s), with metal rectifier cell

A.C. voltages (radio frequency), with thermo-couple

temperatures, with thermo-couple

valve voltmeters (*frequency up to 15 Mc/s*)

apparatus for determining the colour-fastness of textiles

FILM APPARATUS, PARTS AND ACCESSORIES

complete sound recording installations for film studios (35-mm film)

photographic sound recording apparatus

mixing and post-synchronising apparatus with interlock system

microphones, amplifiers

apparatus for sound reproduction (*Film-phonos*)

Philips-Miller sound recording apparatus for radio broadcasts (7-mm film)

twin recording and reproducing machines

twin reproducing machines

editing tables

amplifiers

cutting tape

complete soundfilm reproducing equipments

complete cinema equipments

projectors, sound-heads, lamp-houses, devices for slide projection, twin projectors with super high-pressure mercury lamps

amplifiers

loudspeakers, loudspeaker horns, baffle-boards, rectifiers, saving-stabilisers, arc-lamp resistances, projection screens

transportable reproducing equipments

INSTALLATIONS FOR SOUND-AMPLIFICATION AND IMPROVEMENT OF ACOUSTICS

permanent installations for

buildings, ships, large grounds, etc.

communication between rooms

transportable installations for

meetings, demonstrations, races, etc.

microphones

carbon microphones

ribbon microphones

crystal microphones

amplifiers

push-pull amplifiers in class A, AB and B connection

loudspeakers

moving coil with permanent magnet

cone loudspeakers

diaphragm loudspeakers

crystal loudspeakers

stands, preamplifiers, mixers, matching elements

horns, baffle-boards, sound diffusers, units for panel construction, combination cabinets, petrol aggregates, converters

APPARATUS FOR V.F. AND H.F. LONG DISTANCE TELEPHONY AND TELEGRAPHY VIA CABLES, OVERHEAD LINES OR WIRELESS COMMUNICATIONS

installations for carrier telephony

loading coils for

V.F. and H.F. telephony and telegraphy lines

line amplifiers

4-wire, 2-wire and programme amplifiers

repeater valves

indirectly and directly heated

transformers

signalling converters

secrecy equipment

echo suppressors

measuring apparatus for telephone purposes

supply systems for telephone repeater stations

ARTICLES FOR HEAVY CURRENT ENGINEERING

rectifiers (*oxide cathode, mercury pool and selenium rectifiers*) for industrial applications (*D.C. motors, excitation of magnetic chucks, magnets, etc.*)

charging of batteries

cinema installations

welding machines with accessories for

arc welding

D.C. welding (welding rectifiers)

D.C. and A.C. welding (dual-current plant)

A.C. welding (welding transformers)

resistance welding (*spot welding, seam welding and butt welding machines*)

automatic switches for resistance welding machines

spot lights for spot welding machines

coated welding electrodes for

welding wrought iron, mild steel, cast iron, stainless and heat-resisting steels, aluminium, depositing wear-resisting bronze and copper surfaces

automatic voltage regulators for precision control of the output voltage of generators

condensers

for improving the power-factor

for starting up single-phase motors

for applications in the field of high tension engineering

magnetic oil filters

PRODUCTS OF THE ALLIED INDUSTRIES

corrugated cardboard, single and double pasted in rolls and sheets

corrugated cardboard containers

packing paper in rolls

diamond dies

articles of artificial resin:

moulded pieces for industrial purposes

constructional and insulating material

house fittings and sanitary articles

packing, advertising and luxury articles

household articles

glass for industrial purposes, in the form of

bulbs and glass containers

cane- and tubing glass

gases

hydrogen, air, nitrogen, oxygen, helium, neon,

argon, krypton and xenon

objects made of ceramic material (*magnesium, aluminium, zirconium oxide, soapstone*) in the form of tubes, bars, sheets, rings, crucibles

metals

wear-resisting steel (*sand blasting installations*)

fireproof steel (*boiler grids*)

hafnium, zirconium, titanium, molybdenum,

tungsten

joints (*between two parts of an apparatus which are made of different materials*)

glass—chrome-iron

heat-resisting glass—quartz